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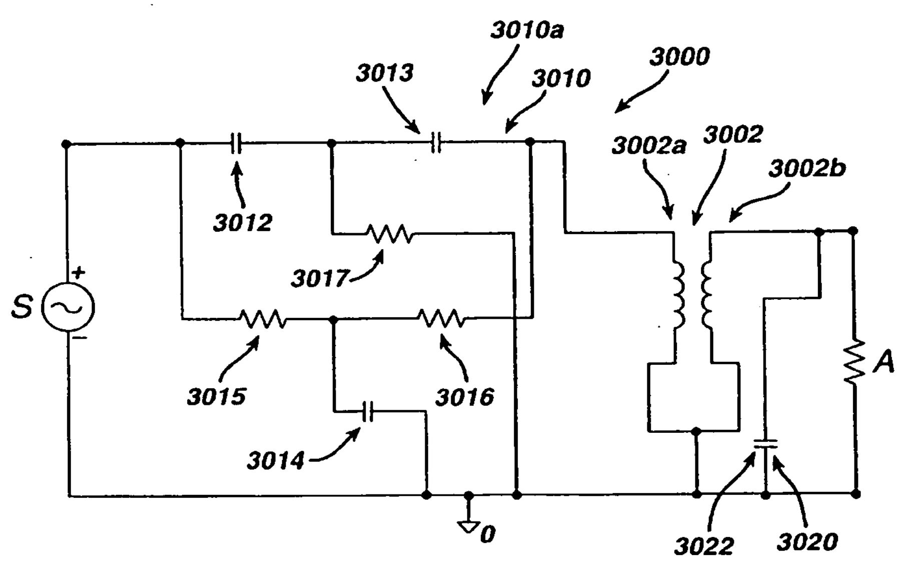
(54) Title: APPARATUS AND METHODS FOR ENHANCING ELECTRONIC AUDIO SIGNALS



(57) **Abstract:** The present invention is a method and apparatus for simply and inexpensively enhancing an electronic audio signal in such a way that the quality of audible sound produced from the audio signal more closely approaches that of the original sound heard live in an acoustically designed environment. The present invention restores the perception of hamonics that are normally missing in an electronic audio signal. The apparatus comprises a passive circuit that causes an input audio signal to be distored such that an enhanced audio signal is produced that exhibits an improved harmonic quality compared to that of the original input audio signal. The passive circuit comprises transformer structure comprising first coil structure and second coil structure, and at least one complex impedance circuit.

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APPARATUS AND METHODS FOR ENHANCING ELECTRONIC AUDIO SIGNALS

Cross-Reference to Related Applications

This application claims the priority of Provisional Application U.S. Serial No. 60/174,423, filed January 4, 2000, and entitled APPARATUS AND METHODS FOR ENHANCING ELECTRONIC AUDIO SIGNALS and Provisional Application U.S. Serial No. 60/169,596, filed December 8, 1999, and entitled APPARATUS AND METHODS FOR ENHANCING ELECTRONIC AUDIO SIGNALS.

FIELD OF THE INVENTION

The present invention relates to the enhancement of electronic audio signals to improve the quality of sound produced from those signals, and more particularly to an apparatus and method for harmonically enhancing an electronic audio signal using a passive circuit element.

BACKGROUND OF THE INVENTION

It is usually considered more pleasurable to hear music, singing or other such complex sounds live, in an acoustically designed environment, rather than hearing the same sound after it has been converted into an electronic audio signal and re-converted back into audible sound.

Many of the sounds we hear, especially musical notes, are often a composite. For example, a musical note having a basic pitch or fundamental frequency, usually contains components of the fundamental frequency called harmonics. These harmonics create the tonal quality or timbre of the sound, such as a musical note, that is often unique to the musical instrument or other sound-producing source. In other words, these harmonics enrich the sound we hear. Numerous sound reproduction systems have been developed in an attempt to add harmonic enhancement to audio signals. However, these systems are often very

sophisticated and expensive and the sound quality produced with such systems still falls short of the perceived quality of the original sound heard live in an acoustically designed environment.

A relatively unsophisticated and inexpensive system has been developed which produces an enhanced electronic audio signal which, when converted into audible sound, exhibits an improved harmonic quality compared to that of the original input audio signal and has been perceived as more closely duplicating the experience of hearing the original live sound in an acoustically designed environment. This system is disclosed in U.S. Patent No. 5,361,306, which is assigned to the assignee of the present application. The exemplary circuits disclosed in the 5,361,306 patent are active circuits that include an input stage having a field inducing coil and an output stage having an electromagnetic field receptor (e.g., another coil) and an output. Input audio signals are transmitted through the inducing coil to set-up an electromagnetic field. The field inducing coil and the electromagnetic field receptor are weakly coupled such that when an input audio signal is transmitted through the field-inducing coil, an enhanced audio signal is available at the output.

The present invention is an improvement to the inventions disclosed in the 5,361,306 patent.

SUMMARY OF THE INVENTION

In accordance with the present invention, a number of methods and apparatus are provided for simply and inexpensively enhancing an electronic audio signal in such a way that the quality of audible sound produced from the audio signal more closely approaches that of the original sound heard live in an acoustically designed environment.

In one aspect of the present invention, an apparatus is provided for enhancing the quality of an input audio signal made up of frequency components within a band of frequencies having a low end and a high end. An apparatus, according to the principles of the present invention, includes a passive circuit that

causes such an input audio signal, transmitted therethrough, to be distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal. This distortion can be a non-uniform amplification of frequency components of the input audio signal or a uniform amplification of the frequency components with a non-uniform attenuation of the frequency components. The distortion is varied in such a manner that the human ear is able to better perceive or pick up and register the harmonic character of the audio signal. The present invention enhances the harmonic character of an electronic audio signal by compensating for one or both of two of the most dominant human hearing phenomena that determine the quality of perceived sound.

Human hearing is typically most sensitive (sound appears to be the loudest) at some frequencies (i.e., sensitive frequencies) and less sensitive (sound appears to be quieter) at other frequencies (i.e., insensitive frequencies). This pitch-loudness phenomenon appears to be an "inner" ear effect. In the other human hearing phenomenon, the outer ear (as well as portions of the inner ear, e.g., Basilar membrane) tends to mask or suppress tones of lesser intensity when presented together with tones of greater intensity. This suppression phenomenon or masking effect appears to be more pronounced at higher frequencies.

The present invention compensates for the pitch-loudness effect by non uniformly distorting an electronic audio signal so that the resulting audible sound is perceived as being louder at the insensitive frequencies. This enhancing distortion can be accomplished by non-uniformly amplifying the audio signal so as to selectively amplify such insensitive frequencies. This enhancing distortion can also be accomplished by uniformly amplifying the audio signal and then selectively reducing or attenuating the amplitude of the sensitive frequencies non-uniformly. The present invention can also be made to create an impulse response that "unmasks" the typically masked tones by stretching the tone in the time domain (i.e., increasing the time smear or dwell time) long enough to be heard but not so long as to be "blurred." In human hearing, the longer a sound is heard, the louder

it seems. The human hearing system also tends to mask weaker sounds that appear too close in time to stronger sounds. This masking phenomenon is known as temporal masking. The human ear is typically sensitive to sounds as short in duration as about 0.1 milliseconds. Therefore, the present invention typically stretches impulses to at least about 0.1 milliseconds in duration. How much the tone needs to be time smeared to be perceived and how much the tone can be time smeared before becoming perceptively blurred will likely vary from listener to listener.

Put another way, the present invention can provide an amplitude shaping function that overcomes both the pitch-loudness phenomenon and the suppression phenomenon, preferably, by providing a linear circuit that possesses two apparently contradictory impulse response characteristics. The impulse response characteristics sought are: (1) a relatively long lasting impulse response and (2) an impulse response with a wide-band characteristic. Conventional thinking teaches that these two characteristics are contradictory in real filters and, hence, unobtainable. High frequency characteristics are revealed by the zero crossings of the impulse response of a linear system. The first zero crossing of the ideal impulse response appears at ½ f_c where f_c is the cutoff frequency of the linear system. For example, a theoretically ideal low pass filter with a bandwidth from 0 Hz to 20 kHz will have zero crossings in its impulse response at about 25 microseconds. What is sought is (1) zero crossings that are relatively close together, e.g., 25 microseconds indicating good high frequency response and (2) relatively long impulse responses, e.g., 1 microseconds or longer. Furthermore, the sharp cutoff characteristic of such an ideal filter extends the impulse response in time with many oscillations.

The passive circuits of the present invention can have an oscillating impulse response. Not intending to be so limited, an exemplary passive circuit of the present invention, with an oscillatory impulse response, can have zero crossings at approximately 30 and 60 micro-seconds and a total duration of over 150 micro-seconds. Thus, the present invention can offer a broadband passive circuit that

exhibits the characteristics of both high frequency content and long duration (i.e., time smear or dwell time).

Even the most staccato audio (e.g., musical) passage has a finite duration (theoretically, an impulse signal has zero duration). Therefore, with the present invention, the actual response to even the subtlest sound can be made of a duration significant enough to be effectively heard but will not be stretched so long as to be shrouded and blurred.

Furthermore, the present passive circuit can be classified in the special class of filters known as minimum-phase filters. The frequency response of a minimum-phase filter may be defined in terms of two components, the magnitude (amplitude) response and the phase response. The magnitude response and phase response of the filter are uniquely related to each other, in that if one is given, the other component can be computed uniquely.

In one embodiment of the present invention, the distortion of the frequency components in the input audio signal is an amplification of the frequency components that increases as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency. The intermediate frequency may also be referred to as a reference frequency. Above the peak high frequency, it may be desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high-end frequency. Instead of the peak high frequency being a single frequency, it may be desirable for the peak high frequency to be a range of frequencies such that the frequency components falling within the range have generally the same amplitude. The peak high frequency may be in the range of from about 10.0 KHz to about 20.0 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.25 times to about 6.0 times the amplification of an intermediate frequency component.

In another embodiment of the present invention, the distortion of the frequency components in the input audio signal is an amplification of the frequency components that increases as the frequency components increase in

frequency from a first intermediate frequency up to a peak high frequency and decrease in frequency from a second intermediate frequency down to a peak low frequency. The first and second intermediate frequencies may be referred to as first and second reference frequencies. The first and second intermediate frequencies may be the same frequency or different frequencies. Above the peak high frequency, it may be desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high-end frequency. Below the peak low frequency, it may be desirable for the amplification to decrease as the frequency components decrease in frequency from the peak low frequency down to the low-end frequency.

Instead of each being a single frequency, it may be desirable for the peak high frequency, the peak low frequency or both to be a range of frequencies such that frequency components falling within each range have generally the same amplitude. The peak high frequency may be in the range of from about 10.0 KHz to about 20.0 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.25 times to about 6.0 times the amplification of the first intermediate frequency component. The peak low frequency may be in the range of from about 20 Hz to about 1 KHz. Amplification of the frequency component(s) at the peak low frequency may be from about 1.1 times to about 3.0 times the amplification of the second intermediate frequency component. The intermediate frequency may be in the range of from about 501 HZ to about 8018 HZ.

In accordance with a first aspect of the present invention, a passive circuit is provided for enhancing the quality of an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a low end and a high end. The passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by distorting audible frequency components of the input audio signal such that the audible frequency components increase in amplitude as they decrease in frequency from an intermediate frequency down to a low frequency, and wherein audible sound

reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal. The passive circuit may comprise transformer structure; and a complex impedance circuit coupled with the transformer structure for defining with the transformer structure the location of the low frequency.

The passive circuit may distort the input signal, when transmitted therethrough, into an enhanced audio signal by amplifying the audible frequency components of the input audio signal such that the amplification increases as the audible frequency components decrease in frequency from the intermediate frequency down to the low frequency.

The transformer structure may comprise first coil structure and second coil structure.

The complex impedance circuit may comprise one of the following: a capacitor in series with the first coil structure; a twin-T network in cascade with the first coil structure; a bridge-T network in cascade with the first coil structure; a capacitor, an inductor and a resistor in parallel with one another and together being in series with the first coil structure; or a capacitor, an inductor and a resistor in parallel with one another and together being in cascade with the second coil structure.

The complex impedance circuit and the transformer structure may function together to primarily effect the distortion of the input signal as defined by a portion of a frequency response curve, the frequency response curve portion sloping upward in amplitude from the intermediate frequency to the low frequency.

The low frequency is a peak low frequency and may be in the range of from about 20 Hz to about 1.0 KHz.

The frequency component at the low frequency may have an amplitude that is from about 1.5 times to about 3.0 times the amplitude of the intermediate frequency.

The input audio signal is a converted form of an original sound, and the

passive circuit is operatively adapted to distort the input audio signal such that audible sound reproduced from the enhanced audio signal sounds perceptively closer to the original sound heard live in an acoustically designed environment than audible sound reproduced from the input audio signal heard in the same acoustically designed environment.

The passive circuit is operatively adapted such that when the input audio signal is of music provided from a compact optical disc and the resulting enhanced audio signal is recorded onto a cassette magnetic tape, the passive circuit imparts an enhancement to the input audio signal such that audible music reproduced from the enhanced audio signal on the cassette tape is clearer and exhibits an improved sound source separation compared to audible music reproduced from the input audio signal on the compact optical disc.

The low frequency may comprise a peak low frequency, and there may be a total of only two significant amplitude peaks between the low end and the high end.

The low frequency may comprise a peak low frequency, and there may be a total of only two significant amplitude peaks in the range of normal human hearing.

The transformer structure and the complex impedance circuit may be positioned between an audio signal source and an amplifier. The audio signal source may comprise a CD player, a DAT player, a laser disc player, and a tape player.

It is also contemplated that the transformer structure and the complex impedance circuit may be positioned between an amplifier and a speaker.

In accordance with a second aspect of the present invention, a passive circuit is provided for enhancing the quality of an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a low end and a high end. The passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by distorting audible frequency components of the input audio signal such that the audible frequency

components increase in amplitude as they increase in frequency from an intermediate frequency up to a high frequency, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal. The passive circuit may comprise transformer structure; and a complex impedance circuit coupled with the transformer structure for defining with the transformer structure the location of the high frequency.

The passive circuit may distort the input signal, when transmitted therethrough, into an enhanced audio signal by amplifying the audible frequency components of the input audio signal such that the amplification increases as the audible frequency components increase in frequency from the intermediate frequency up to the high frequency.

The transformer structure may comprise first coil structure and second coil structure. The complex impedance circuit may comprise a capacitor in parallel with the second coil structure.

The transformer structure may comprise a transformer comprising first and second coils. The first coil defines the first coil structure and the second coil defines the second coil structure. The second coil and the complex impedance circuit may function together to primarily effect the distortion of the input signal as defined by a portion of a frequency response curve. The portion slopes upward in amplitude from the intermediate frequency to the high frequency.

The high frequency may comprise a peak high frequency, and there may be a total of only two amplitude peaks between the low end and the high end.

The high frequency may comprise a peak high frequency, and there may be a total of only two amplitude peaks in the range of normal human hearing.

The transformer structure and the complex impedance circuit may be positioned between an audio signal source and an amplifier. The audio signal source may comprise a CD player, a DAT player, a laser disc player, and a tape player.

Alternatively, the transformer structure and the complex impedance

circuit may be adapted to be positioned between an amplifier and a speaker.

In accordance with a third aspect of the present invention, a passive circuit is provided for enhancing the quality of an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a low end and a high end. The passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by distorting audible frequency components of the input audio signal such that a first set of the audible frequency components increase in amplitude as they decrease in frequency from a first intermediate frequency down to a low frequency and a second set of audible frequency components increase in amplitude as they increase in frequency from a second intermediate frequency up to a high frequency, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal. The passive circuit may comprise: transformer structure; a first complex impedance circuit coupled with the transformer structure for defining with the transformer structure the location of the low frequency; and a second complex impedance circuit coupled with the transformer structure for defining with the transformer structure the location of the high frequency.

The transformer structure may comprise first coil structure and second coil structure.

The first complex impedance circuit may comprise one or more of the following: a capacitor in series with the first coil structure; a twin-T network in cascade with the first coil structure; a bridge-T network in cascade with the first coil structure; a capacitor, an inductor and a resistor in parallel with one another and together being in series with the first coil structure; or a capacitor, an inductor and a resistor in parallel with one another and together being in cascade with the second coil structure.

The second complex impedance circuit may comprise a capacitor in parallel with the second coil structure.

The first complex impedance circuit and the transformer structure may

function together to primarily effect the distortion of the input signal as defined by a first portion of a frequency response curve. The first portion slopes upward in amplitude from the first intermediate frequency to the low frequency, and the second complex impedance circuit and the transformer structure may function together to primarily effect the distortion of the input signal as defined by a second portion of the frequency response curve. The second portion slopes upward in amplitude from the second intermediate frequency to the high frequency.

The first portion of the frequency response curve may slope non-linearly upward in amplitude from the first intermediate frequency to the low frequency and the second portion of the frequency response curve may slope non-linearly upward in amplitude from the second intermediate frequency to the high frequency. The first intermediate frequency and the second intermediate frequency may comprise the same frequency or different frequencies.

The passive circuit may distort the input signal, when transmitted therethrough, into an enhanced audio signal by amplifying the audible frequency components of the input audio signal such that the amplification increases as the audible frequency components increase in frequency from the first intermediate frequency down to the low frequency, and from the second intermediate frequency up to the high frequency.

The passive circuit may distort a substantial number of the audible frequency components of the input audio signal such that a first set of the substantial number of audible frequency components increase in amplitude as they decrease in frequency from the first intermediate frequency down to the low frequency and a second set of the substantial number of the audible frequency components increase in amplitude as they increase in frequency from the second intermediate frequency up to the high frequency.

The passive circuit may distort the input signal, when transmitted therethrough, into an enhanced audio signal by non-uniformly amplifying the audible frequency components of the input audio signal. The passive circuit may

distort a majority of the frequency components.

The passive circuit may be incorporated within a cable/passive circuit assembly.

The passive circuit may be coupled to an input audio signal source via a connector.

The transformer structure and the first and second complex impedance circuits may be positioned between an audio signal source and an amplifier. Alternatively, the transformer structure and the first and second complex impedance circuits may be positioned between an amplifier and a speaker.

In accordance with a fourth aspect of the present invention, a method is provided for enhancing the quality of electronic audio signals, comprising the steps of: providing an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a high end and a low end; providing a passive circuit comprising transformer structure and a complex impedance circuit coupled to the transformer structure; and passively distorting the input audio signal into an enhanced audio signal by passing the input audio signal through the passive circuit to distort frequency components of the input audio signal such that the frequency components increase in amplitude as they decrease in frequency from an intermediate frequency down to a low frequency. The location of the low frequency is defined by the complex impedance circuit together with the transformer structure, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal.

In accordance with a fifth aspect of the present invention, a method is provided for enhancing the quality of electronic audio signals, comprising the steps of: providing an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a high end and a low end; providing a passive circuit comprising transformer structure and a complex impedance circuit coupled to the transformer structure; and passively distorting the input audio signal into an enhanced audio signal by passing the input audio signal through a

passive circuit to distort frequency components of the input audio signal such that the frequency components increase in amplitude as they increase in frequency from an intermediate frequency up to a high frequency. The location of the high frequency is defined by the complex impedance circuit together with the transformer structure, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal.

In accordance with a sixth aspect of the present invention, a method is provided for enhancing the quality of electronic audio signals, comprising the steps of: providing an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a high end and a low end; providing a passive circuit comprising transformer structure, a first complex impedance circuit coupled to the first coil structure and a second complex impedance circuit coupled to the second coil structure; and passively distorting the input audio signal into an enhanced audio signal by passing the input audio signal through a passive circuit to distort frequency components such that a first set of the frequency components increase in amplitude as they decrease in frequency from a first intermediate frequency down to a low frequency and a second set of the frequency components increase in amplitude as they increase in frequency from a second intermediate frequency up to a high frequency, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal.

The present method can include the step of processing one or more of the enhanced audio signals into sound. The scope of the present invention is intended to include the sound that is so produced. The present enhanced audio signal and the sound produced therefrom includes audio signals and sounds having frequency components which fall within the range or bandwidth of normal human hearing (i.e., approximately 20 Hz to 20KHz). In addition, it has been found that the shape of the frequency response curve can depend upon the bandwidth used in modern audio systems. For example, it can be desirable for the present invention

to be designed to process bandwidths that are narrower (e.g., greater than 0 HZ to about 3 KHZ) than that of normal human hearing. When such narrower bands of frequencies are to be enhanced according to the present invention, it has been found that it can be desirable to maintain the same basic shape of the frequency response curve (e.g., with the same number of peak and intermediate frequencies as that used to enhance broader bands of frequencies) used to enhance a broader bandwidth of frequencies, only sized to fit the narrower bandwidth, rather than cutting off the portions of the broader frequency response curve that extend beyond the narrower bandwidth.

Thus, the circuits (i.e., frequency response curves) of the present invention can be optimized for application to audio signals consisting of spectra essentially covering the classical audio bandwidth of approximately 20 Hz to 20 KHz, as well as for use with many modern systems that contain audio signals of differing bandwidths. For example (1) analog telephone signals consist of spectra covering essentially 300 Hz to 3000 Hz, (2) Voice over Internet Protocol (VoIP) is limited to essentially 8 KHz and (3) streaming audio is subject to other bandwidth restrictions. Bandwidth can be a precious commodity in such applications.

The present method can also include the step of transmitting one or more audio signals, enhanced according to the present invention, from one location to another. The present method can further include the step of recording one or more of the present enhanced audio signals onto a recording medium. The scope of the present invention is also intended to include the recording medium having one or more of the present enhanced audio signals recorded thereon. The recording medium can be a magnetic recording medium (e.g., reel-to-reel tape, cassette tape, magnetic disk, etc.) or an optical recording medium (e.g., compact disk, video disk, etc.). The present invention is not intended to be limited to any particular type of recording medium or method of recording thereon.

The present invention provides an apparatus and method for enhancing the harmonic quality of an electronic audio signal, in particular an audio signal having a complex wave form (i.e., multiple frequency components such as, for

example, music, singing, speech, animal sounds, naturally occurring sounds, equipment noises, and the like. An audio signal enhanced according to the present invention exhibits an improved harmonic quality compared to that of the input electronic audio signal. It has been found that a similar harmonic enhancement can be obtained using the circuits disclosed in U.S. Patent No. 5,361,306; U.S. Patent Application Serial No. 08/472,876, having a filing date of June 7, 1995 and entitled APPARATUS AND METHOD OF ENHANCING ELECTRONIC AUDIO SIGNALS; U.S. Patent Application Serial No. 08/700,728, having a filing date of August 13, 1996 and entitled APPARATUS AND METHODS FOR THE HARMONIC ENHANCEMENT OF ELECTRONIC AUDIO SIGNALS;U.S. Patent Application Serial No. 08/909,807, having a filing date of August 12, 1997 and entitled APPARATUS AND METHODS FOR THE HARMONIC ENHANCEMENT OF ELECTRONIC AUDIO SIGNALS; U.S. Patent Application Serial No. 08/989,373, having a filing date of December 12, 1997 and entitled APPARATUS AND METHODS FOR ENHANCING ELECTRONIC AUDIO SIGNALS; and U.S. Patent Application Serial No. 09/431,371, having a filing date of November 1, 1999 and entitled DIGITAL FILTER, the disclosures of which are incorporated herein by reference.

The present teachings and disclosure reveal that there are a variety of other ways of obtaining the same or a similar harmonic enhancement in an electronic audio signal. Having been provided with the teachings and the exemplary circuits disclosed herein, it will be a matter of simple trial and error experimentation, if any, for one of ordinary skill in the art to design additional ways to produce the same or a similar enhancing effect. Accordingly, the general and specific circuits disclosed herein are examples only and the present invention is not intended to be so limited.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a transformer constructed in accordance with

a first embodiment of the present invention;

Fig. 2 is a perspective view of the bobbin of the transformer illustrated in Fig. 1;

Fig. 3 is a view taken along view line 3-3 in Fig.1;

Fig. 4 is a schematic side view of the bobbin illustrated in Fig. 3;

Fig. 5 is a circuit diagram of a passive circuit constructed in accordance with a first embodiment of the present invention coupled to an audio signal source and an audio amplifier;

Fig. 6 is an exploded view of two E-core sections and two I-core sections of the core illustrated in Fig. 1;

Fig. 7 is an illustration of first, second and third frequency response curves generated by a passive circuit constructed in accordance with a first embodiment of the present invention;

Fig. 7A is an illustration of a frequency response curve generated by a passive circuit adapted for use in a CB radio;

Figs. 7B and 7C are front and side views, respectively, of a bobbin to be incorporated into a transformer forming part of a passive circuit adapted for use in a CB radio;

Fig. 7D is a circuit diagram of a passive circuit for effecting the response of Fig. 7A;

Fig. 8 is a circuit diagram of a passive circuit constructed in accordance with a second embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 9 is a perspective view of a first transformer constructed in accordance with a second embodiment of the present invention;

Fig. 10 is a perspective view of the bobbin of the transformer illustrated in Fig. 9;

Fig. 10A is a schematic side view of the bobbin illustrated in Fig.10;

Fig. 11 is a view taken along view line 11-11 in Fig. 9;

Fig. 12 is a perspective view of a second transformer constructed in

accordance with a second embodiment of the present invention;

Fig. 13 is a perspective view of the bobbin of the transformer illustrated in Fig. 12;

Fig. 13A is a schematic side view of the bobbin illustrated in Fig.13;

Fig. 14 is a view taken along view line 14-14 in Fig. 12; and

Fig. 15 is an illustration of first, second and third frequency response curves generated by a passive circuit constructed in accordance with a second embodiment of the present invention;

Fig. 16 is a circuit diagram of a passive circuit constructed in accordance with a third embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 17 is a front view of a bobbin used in forming a transformer of the passive circuit of Fig. 16;

Fig. 18 is a side view of the bobbin illustrated in Fig. 17;

Fig. 19 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a third embodiment of the present invention;

Fig. 19A is a perspective view of a cable/passive circuit assembly of the present invention;

Fig. 19B is a circuit diagram of the cable/passive circuit assembly illustrated in Fig. 19A;

Fig. 20 is a circuit diagram of a passive circuit constructed in accordance with a fourth embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 21 is a front view of a bobbin used in forming a transformer of the passive circuit of Fig. 20;

Fig. 22 is a side view of the bobbin illustrated in Fig. 21;

Fig. 23 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a fourth embodiment of the present invention;

Fig. 24 is a circuit diagram of a passive circuit constructed in accordance with a fifth embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 25 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a fifth embodiment of the present invention;

Fig. 26 is a circuit diagram of a passive circuit constructed in accordance with a sixth embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 27 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a sixth embodiment of the present invention;

Fig. 28 is a circuit diagram of a model passive circuit including a twin-T network;

Fig. 29 is an illustration of an example frequency response curve generated by a model passive circuit including a twin-T network;

Fig. 30 is a circuit diagram of a passive circuit constructed in accordance with a seventh embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 31 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a seventh embodiment of the present invention;

Fig. 32 is a circuit diagram of a passive circuit constructed in accordance with an eighth embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 33 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with an eighth embodiment of the present invention;

Fig. 34 is a circuit diagram of a passive circuit constructed in accordance with a ninth embodiment of the present invention coupled to an audio source and

an audio amplifier;

Fig. 35 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a ninth embodiment of the present invention;

Fig. 36 is a circuit diagram of a passive circuit constructed in accordance with a tenth embodiment of the present invention coupled to an audio source and an audio amplifier;

Fig. 37 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with a tenth embodiment of the present invention;

Fig. 38 is a circuit diagram of a passive circuit constructed in accordance with an eleventh embodiment of the present invention coupled to an audio amplifier and a speaker;

Figs. 38A and 38B are front and side views, respectively, of a bobbin incorporated into a transformer forming part of the passive circuit of Fig. 38; and

Fig. 39 is an illustration of a frequency response curve generated by a passive circuit constructed in accordance with an eleventh embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Although the present invention is herein described in terms of specific embodiments, it will be readily apparent to those skilled in this art that various modifications, re-arrangements, and substitutions can be made without departing from the spirit of the invention. The scope of the present invention is thus only limited by the claims appended hereto.

Each of the particular exemplary embodiments disclosed in the present application produces an enhancement of an electronic audio signal. An apparatus, according to the principles of the present invention, comprises a passive circuit capable of distorting an input audio signal transmitted therethrough by non-linearly (i.e., non-uniformly) amplifying enhancing harmonics or frequency

components in the input audio signal. By increasing the amplitude of enhancing harmonics in this manner, the resulting enhanced audio signal exhibits an improved harmonic quality compared to that of the input audio signal.

The present circuit is operatively adapted to accomplish enhancement without using any active elements such as operational amplifiers, transistors, vacuum tubes, etc. Thus, the passive circuit does not add power to the input audio signal.

Exemplary Embodiment No. 1

A passive circuit 5 for enhancing an electronic audio signal, constructed in accordance with a first embodiment of the present invention, is illustrated in the circuit diagram of Fig. 5. The circuit 5 comprises a single transformer 10. The transformer 10 includes a bobbin 20, a ferromagnetic core 30 and two magnetically coupled coils 40 and 42, see Figs. 1-3 and 5.

The bobbin 20 may be formed from a fiber reinforced polymeric material. In the illustrated embodiment, the bobbin 20 comprises a glass fiber reinforced nylon. The bobbin 20 has a substantially rectangular-shaped tubular portion 22 having a core-receiving aperture 22a extending through it. Provided at opposite ends of the tubular portion 22 are first and second flanges 24 and 26. The wall thickness of each of the tubular portion 22 and the flanges 24 and 26 is about .040 inch. The width W_F and length L_F of each flange 24 and 26 are about 1.48 inches and 1.54 inches, respectively. The width W_A, height H_A and length L_A of the aperture 22a are about .765 inch, 1.02 inches, and .765 inch, respectively. Each of the flanges 24 and 26 includes a pin-containing portion 24a and 26a having six L-shaped pins embedded therein. The twelve pins are designated in the drawings P_1-P_{12}. One such bobbin is commercially available from Plastron Corporation under the product designation "94HB."

The first coil 40 is defined by first and second primary winding portions 40a and 40b which are connected in series, see Fig. 5. The second coil 42 is defined

by first and second secondary winding portions 42a and 42b which are connected in series.

A first wire 44, a type "39single-poly-nylon(SPN)155°C" wire, wherein "39" is the wire gauge, "SPN" is the outer coating material, and "155°C" is the wire temperature rating, is randomly wound in a clockwise direction about the tubular portion 22 to form the first primary winding portion 40a. The winding portion 40a comprises 1000 turns and has a DC resistance of about 285 Ohms ± 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Figs. 2, 4 and 5. A first layer 51 of a fiber reinforced polymeric film is wrapped about the first primary winding portion 40a, see Fig. 3. In the illustrated embodiment, the film comprises a glass fiber reinforced polyester film having a thickness of about .0065 inch. Such a film is commercially available from TESA Inc. under the product designation "IL-4426." The first layer 51 has a thickness of about .0065 inch.

A second wire 48, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer 51 so as to form the first secondary winding portion 42a. The winding portion 42a comprises 2000 turns and has a DC resistance of about 156 Ohms ± 10%. It is soldered or otherwise connected to pins P_7 and P_9. A second layer 53 of the fiber reinforced polymeric film described above is wrapped about first secondary winding portion 42a, see Fig. 3. The second layer 53 has a thickness of about .013 inch.

A third wire 50, a type "39SPN155°C" wire, is randomly wound in a clockwise direction about the second film layer 53 so as to form the second primary winding portion 40b. The winding portion 40b comprises 1000 turns and has a DC resistance of about 335 Ohms ± 10%. It is soldered or otherwise connected to pins P_3 and P_6. A third layer 55 of the fiber reinforced polymeric film is wrapped about second primary winding portion 40b, see Fig. 3. The third layer 55 has a thickness of about .013 inch. The first and second primary winding portions 40a and 40b are connected in series via pin P_3 so as to define the first coil 40 extending between pins P_1 and P_6.

A fourth wire 52, a type "34SPN155°C" wire, is randomly wound in a

counter-clockwise direction about the third film layer 55 so as to form the second secondary winding portion 42b. The winding portion 42b comprises 2000 turns and has a DC resistance of about 186 Ohms ± 10%. It is soldered or otherwise connected to pins P_9 and P_{11}. A fourth layer 57 of the fiber reinforced polymeric film is wrapped about second secondary winding 42b. The fourth layer 57 has a thickness of about .0065 inch. The first and second secondary winding portions 42a and 42b are connected in series via pin P_9 so as to define the second coil 42 extending between pins P_7 and P_{11}.

The first, second, third and fourth wires 44, 48, 50 and 52 are commercially available from the Phelps Dodge Corporation.

The core 30 is formed from numerous E-core and I-core sections 32 and 34, see Figs. 1, 3 and 6. The sections 32 and 34 comprise a ferromagnetic material, such as a 24 gauge, M50 grade steel. The sections 32 and 34 are assembled by stacking the E-core and I-core sections 32 and 34 alternatively so that each I-core section 34 lies between adjacent E-core sections 32, see Fig. 6. A single I-core section 34 may be laminated to each E-core section 32 before assembly. Center portions 32a of the E-core sections 32 fill the core-receiving aperture 22a of the bobbin 20. After assembly, the sections 32 and 34 are laminated to one another by coating the outer surfaces of the assembled sections 32 and 34 with a varnish. Such a varnish is commercially available from P.D. George Co. under the product designation "77X010." In the illustrated embodiment, each E-core section 32 has a thickness of about .025 inch. Each I-core section 34 has a thickness of about .025 inch. The length L_C of the core 30 is about 2.25 inches, the thickness T_C of the core 30 is about .750 inch, and the height H_C of the core 30 is about 1.875 inch, see Fig. 1.

The primary winding portions 40a and 40b are interleaved with the secondary winding portions 42a and 42b so as to achieve a high degree of coupling between the primary winding portions 40a, 40b and the secondary winding portions 42a, 42b as well as to minimize the capacitance between the winding portions 40a, 40b and 42a, 42b. The transformer 10 is designed with very low flux

density to increase the ability of the transformer 10 to accept low-level audio signals, increase primary inductance, decrease capacitive reactance and increase the overall frequency response of the circuit 5.

The passive circuit 5 is intended to be coupled directly to an audio signal source S, such as a CD player, a laser disc player, a tape player, a radio, a digital audio tape (DAT) player, and to an audio amplifier A, such as a preamplification stage, e.g., a solid state or vacuum tube preamplifier, or a power amplification stage, e.g., an integrated power amplifier, a vacuum tube power amplifier, a solid state power amplifier or a hybrid power amplifier. Any commercially available connector(s) may be used to connect the passive circuit 5 to the signal source including a single-ended connector or a balanced connector. No active element is connected between the source S and the audio amplifier A, see Fig. 5. It has been found that when the transformer 10 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the transformer 10, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal. This distortion is a non-linear amplification of at least a portion of the frequency components of the input audio signal. The amplification is preferably varied in such a manner that the human ear is able to better perceive or pick up and register the harmonic character of the audio signal. For example, the frequency components near the high end of the band of frequencies may be amplified by an amount which exceeds the amount by which intermediate frequency components between the low and high ends of the band of frequencies are amplified.

In Fig. 7, first, second and third exemplary frequency response curves C_1, C_2, C_3, generated by a passive circuit 5 constructed in accordance with the illustrated embodiment described above, are shown. For each curve, output voltages are plotted versus frequency for normalized input audio signals. The frequency response curves C_1, C_2, C_3 were obtained by connecting the first coil 40 of the transformer 10 to a signal source S, a conventional signal generator, which

generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22 KHz and connecting the second coil 42 of the transformer 10 to resistive loads of 20 KOHMS (Curve C_1), 50 KOHMS (Curve C_2), and 100 KOHMS (Curve C_3), which loads represented equivalent impedances that the transformer 10 might see when connected to the inputs of conventional audio amplifiers. No active element was interposed between the input source S and any one of the resistive loads.

Each of the first, second and third curves C_1, C_2, C_3 represents the amplification that occurs to frequency components of an input audio signal when the input audio signal passes through the passive circuit 5 and the output (i.e., the second coil 42) of the passive circuit 5 is connected to a resistive load. The resistive load is 20 KOHMS for curve C_1, 50 KOHMS for curve C_2, and 100 KOHMS for curve C_3. From these three curves C_1, C_2, C_3, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 5. This distortion is a non-linear amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components of the input audio signal can be substantially constant for intermediate frequency components falling within a band of frequencies of about 20 Hz to about 3.5 KHz and increases for frequency components increasing in frequency from about 3.5 KHz up to a peak high frequency of about 20 KHz. Above the peak high frequency of about 20 KHz, the amplification decreases as the frequency components increase in frequency from the peak high frequency of about 20 KHz to a high-end frequency of about 22 KHz. The amplification or gain is between about 1.5 and 2.0 for the intermediate frequency components falling within the band of frequencies of about 20 Hz to about 5 KHz and is between about 2.6 and about 4.8 for frequency components at the peak high frequency. Hence, for Curve C_1, the amplification of the frequency component at the peak high frequency is about 1.5 times the average amplification of a range of intermediate frequency components from 20 Hz to 3.5 KHz. For Curve C_2, the

amplification of the frequency component at the peak high frequency is about 2.0 times the average amplification of a range of intermediate frequency components from 20 Hz to 3.5 KHz. For Curve C_3, the amplification of the frequency component at the peak high frequency is about 2.3 times the average amplification of a range of intermediate frequency components from 20 Hz to 3.5 KHz.

It is believed that the frequency response of the passive circuit 5 for a given load can be varied by changing one or more of the following: the number of turns of one or both of the coils 40 and 42; the size and type of wire used to make up the coils 40 and 42; the DC resistance of one or more of the first and second primary winding portions 40a and 40b and the first and second secondary winding portions 42a and 42b; the size of the core 30; and the gauge and grade of the material used to form the core 30. It is also believed that if the capacitance of the transformer 10 is varied, the amplification of the frequency components at the high end of the band of frequencies may be varied. Capacitance may be altered by changing the thickness of one or more of the film layers 51, 53 and 55; the DC resistance of one or more of the winding portions 40a, 42a, 40b and 42b; and/or the location of one or more of the winding portions 40a, 42a, 40b and 42b. Thus, an empirical determination is required to determine exactly the make up of a transformer 10 in order to effect a desired frequency response when the transformer is coupled to a given load.

Thus, in accordance with a first embodiment of the present invention, an input audio signal is distorted into an enhanced audio signal by passing the input audio signal through a passive circuit 5 to amplify frequency components of the input signal. The amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from an intermediate frequency up to a peak high frequency. Above the peak high frequency, it is desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high-end frequency.

It is further contemplated with regard to the first embodiment of the present invention that instead of the peak high frequency comprising a single frequency, it may be desirable for the peak high frequency to be a relatively narrow range of frequencies such that the frequency components falling within the narrow range have generally the same amplitude.

Curves C_1, C_2 and C_3 are provided for illustrative purposes only. It is believed that the amplification of intermediate frequency components, e.g., those of about 20 Hz to about 3.5 KHz, may be unity gain (1.0), less than 1.0 or greater than 1.0. The peak high frequency may be in the range of from about 6 KHz to about 30 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.5 times to about 3.0 times the amplification of intermediate frequency component or the average amplification of a range of intermediate frequency components.

It is further contemplated that the order of the winding portions 40a, 40b, 42a and 42b may vary so as to shield incoming electromagnetic interference (EMI) and radio frequency interference (RFI) radiation. Thus, the second wire 48 may be wound first on the tubular portion 22 in a counter-clockwise direction, followed by the first wire 44 which is wound in a clockwise direction, followed by the fourth wire 52 which is wound in a counter-clockwise direction, followed by the third wire 50 which is wound in a clockwise direction. Hence, the order of the winding portions is as follows: first secondary winding portion 42a followed by first primary winding portion 40a followed by second secondary winding portion 42b followed by second primary winding portion 40b. The second primary winding portion 40b acts as a shield such that its own flux lines cancel most incoming EMI and RFI radiation.

It is also contemplated that a passive circuit comprising a single or dual transformer may be constructed for use in a CB radio. The single or dual transformer is coupled at its input to the output of a conventional detector circuit within the CB radio through a low pass filter comprising a capacitor in series with a resistor and at its output to an audio amplifier also within the CB radio.

In Fig. 7A, an exemplary frequency response curve, generated by a single transformer passive circuit constructed in accordance with the present invention, is shown. In this curve, output voltages are plotted versus frequency for a normalized input audio signal. The frequency response curve was obtained by connecting the first coil of the transformer, through a low pass filter comprising a capacitor (.22 microfarad) in series with a resistor (250 Ohms), to a signal source S, a conventional signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 20 KHz and connecting the second coil of the transformer to a resistive load of about 43 KOHMS, which load represented an equivalent impedance that the transformer might see when connected to the input of a conventional audio amplifier of a CB radio. No active element was interposed between the input source and the resistive load.

The curve of Fig. 7A represents the amplification that occurs to frequency components of an input audio signal when the input audio signal passes through the passive circuit and the output (i.e., the second coil) of the passive circuit is connected to a resistive load. As noted above, the resistive load is about 43 KOHMS for the curve illustrated in Fig. 7A. From this curve, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components of the input audio signal gradually increases for intermediate frequency components falling within a band of frequencies of from about 100 Hz to about 300 Hz and increases at an increased rate for frequency components increasing in frequency from about 300 Hz up to a peak high frequency of about 10 KHz. Above the peak high frequency of about 10 KHz, the amplification decreases as the frequency components increase in frequency from the peak high frequency of about 10 KHz to a high-end frequency of about 20 KHz. The amplification or gain in the curve of Fig. 7A is in the range of from

about 1.6 and about 1.8 for the intermediate frequency components falling within the band of frequencies of about 100 Hz to about 300 Hz and is about 3.8 for frequency components at or near the peak high frequency.

The curve illustrated in Fig. 7A is provided for illustrative purposes only. It is believed that the amplification of intermediate frequency components, e.g., those of about 100 Hz to about 300 Hz, may be unity gain (1.0), less than 1.0 or greater than 1.0. The peak high frequency may be in the range of from about 6 KHz to about 15 KHz for a single transformer circuit to be used in a CB radio.

The single transformer, when incorporated within a CB radio, will typically receive an input audio signal made up of frequencies components falling only within a range of from about 300 Hz to about 3 KHz.

A peak voltage amplitude limit circuit is coupled to the audio amplifier of the CB radio and also to the modulator of the transmitter within the CB radio. The passive circuit will typically have approximately a 2-3 dB average gain across the frequency band, i.e., from about 10 Hz to about 10KHz. The gain is not uniform as a function of frequency in that it follows the frequency response curve. Since the average gain is larger than unity, the average voltage into the modulator of the transmitter is raised but the peak voltage is not increased because there is a peak voltage amplitude limit circuit in the modulator path. Because the average modulating voltage is higher, the average modulation is higher and the average voice (side band) level is higher. This gives more clarity since the average signal-to-noise level is higher.

A passive circuit for effecting the response shown in Fig. 7A will now be described. It comprises a single transformer that includes a bobbin 200, a ferromagnetic core and two magnetically coupled coils, see Figs. 7B-7D.

The bobbin 200 may be formed from a fiber reinforced polymeric material. In the illustrated embodiment, the bobbin 200 comprises a glass fiber reinforced nylon. The bobbin 200 has a substantially rectangular-shaped tubular portion 220 having a core-receiving aperture 220a extending through it, see Figs. 7B and 7C. Provided at opposite ends of the tubular portion 220 are first and second flanges

240 and 260. The wall thickness of each of the tubular portion 220 and the flanges 240 and 260 is about .035 inch. The width W_F and length L_F of each flange 24 and 26 are about 1.1 inches and .79 inches, respectively. The width W_A, height H_A and length L_A of the aperture 220a are about .515 inch, .395 inch, and .71 inch, respectively. Each of the flanges 240 and 260 includes a pin-containing portion 240a and 260a having four L-shaped pins embedded therein. The eight pins are designated in the drawings P_1-P_8. One such bobbin is commercially available from Plastron Corporation under the product designation "1183A-31-80."

The first coil 400 is defined by first and second primary winding portions 400a and 400b which are connected in series, see Fig. 7D. The second coil 420 is also defined by first and second secondary winding portions 420a and 420b which are connected in series.

A first wire 440, a type "39single-poly-nylon(SPN)155°C" wire, wherein "39" is the wire gauge, "SPN" is the outer coating material, and "155°C" is the wire temperature rating is randomly wound in a clockwise direction about the tubular portion 220 to form the first primary winding portion 400a. The winding portion 400a comprises 375 turns and has a DC resistance of about 71 Ohms ± 10%. It is soldered or otherwise connected to pins P_1 and P_2, see Fig. 7C. A first layer of a fiber reinforced polymeric film is wrapped about the first primary winding portion 400a. In this embodiment, the film comprises a glass fiber reinforced polyester film having a thickness of about .0045 inch. Such a film is commercially available from TESA Inc. under the product designation "IL-51596." The first layer has a thickness of about .0045 inch.

A second wire 480, a type "37SPN155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer so as to form the first secondary winding portion 420a. The winding portion 420a comprises 1500 turns and has a DC resistance of about 145 Ohms ± 10%. It is soldered or otherwise connected to pins P_7 and P_5. A second layer of the fiber reinforced polymeric film described above is wrapped about first secondary winding portion 420a. The

second layer has a thickness of about .0045 inch.

A third wire 500, a type "39SPN155°C" wire, is randomly wound in a clockwise direction about the second film layer so as to form the second primary winding portion 400b. The winding portion 400b comprises 375 turns and has a DC resistance of about 81 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_2 and P_4. A third layer of the fiber reinforced polymeric film is wrapped about second primary winding portion 400b, see Fig. 7D. The third layer has a thickness of about .0045 inch. The first and second primary winding portions 400a and 400b are connected in series via pin P_2 so as to define the first coil 400 extending between pins P_1 and P_4.

A fourth wire 520, a type "37SPN155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer so as to form the second secondary winding portion 420b. The winding portion 420b comprises 1500 turns and has a DC resistance of about 178 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_7 and P_8. A fourth layer of the fiber reinforced polymeric film is wrapped about second secondary winding 420b. The fourth layer has a thickness of about .0045 inch. The first and second secondary winding portions 420a and 420b are connected in series via pin P_7 so as to define the second coil 420 extending between pins P_5 and P_8.

The first, second, third and fourth wires 440, 480, 500 and 520 are commercially available from the Phelps Dodge Corporation.

The core is formed from numerous E-core and I-core sections 32 and 34, see Fig. 6. The sections 32 and 34 comprise a ferromagnetic material, such as a 24 gauge, M50 grade steel. The sections 32 and 34 are assembled by stacking the E-core and I-core sections 32 and 34 alternatively so that each I-core section 34 lies between adjacent E-core sections 32, see Fig. 6. A single I-core section 34 may be laminated to each E-core section 32 before assembly. Center portions 32a of the E-core sections 32 fill the core-receiving aperture 220a of the bobbin 200. After assembly, the sections 32 and 34 are laminated to one another by coating the outer surfaces of the assembled sections 32 and 34 with a varnish. Such a varnish

is commercially available from P.D. George Co. under the product designation "77X010." In the illustrated embodiment, each E-core section 32 has a thickness of about .025 inch. Each I-core section 34 has a thickness of about .025 inch. The length L_C of the core 30 is about 1.625 inches, the thickness T_C of the core 30 is about .375 inch, and the height H_C of the core 30 is about 1.313 inch, same dimensions as shown in Fig. 1.

The passive circuit of Fig. 7D is coupled at pins P_1 and P_4 to the output of a conventional detector circuit within a CB radio through a low pass filter comprising a capacitor in series with a resistor (i.e., the resistor is positioned between the capacitor and the passive circuit) and is coupled at pins P_5 and P_8 to an audio amplifier also within the CB radio.

It is also contemplated that the transformer illustrated in Fig. 7D comprising the first and second coils 400 and 420 may be coupled directly to an audio signal source S, such as a CD player, a laser disc player, a tape player, a radio, a digital audio tape player, and to an audio amplifier A, such as a preamplification stage, e.g., a solid state or vacuum tube preamplifier, or a power amplification stage, e.g., an integrated power amplifier, a vacuum tube power amplifier, a solid state power amplifier or a hybrid power amplifier. That is, the transformer illustrated in Fig. 7D may be connected directly to the signal source. However, if required, a capacitor may be interposed between the transformer and the signal source to block DC voltage. Any commercially available connector(s) may be used to connect the Fig. 7D transformer to the signal source and the amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

Exemplary Embodiment No. 2

A passive circuit 300 comprising first and second transformers 100 and 200, constructed in accordance with a second embodiment of the present invention, is illustrated in the circuit diagram of Fig. 8. The first and second transformers 100 and 200 are constructed in essentially the same manner as the

transformer 10 described above and are illustrated in Figs. 9, 10, 10A and 11 and 12, 13, 13A and 14. The first transformer 100 includes a bobbin 120, see Figs.10 and 10A, a ferromagnetic core 130, see Fig. 9, and two magnetically coupled coils 140 and 142, and see Fig. 8. The second transformer 200 includes a bobbin 220, see Figs. 13 and 13A, a ferromagnetic core 230, see Fig. 12, and two magnetically coupled coils 240 and 242, and see Fig. 8.

The bobbins 120 and 220 are constructed in essentially the same manner as bobbin 20 described above. In the illustrated embodiment, the bobbins 120 and 220 are formed from a glass fiber reinforced nylon.

The bobbin 120 has a substantially rectangular-shaped tubular portion 122 having a core-receiving aperture 122a extending through it. Provided at opposite ends of the tubular portion 122 are first and second flanges 124 and 126. The wall thickness of each of the tubular portion 122 and the flanges 124 and 126 is about .040 inch. The width W_F and length L_F of each flange 124 and 126 are about 1.23 inches and 1.34 inches, respectively. The width W_A, height H_A and length L_A of the aperture 122a are about .640 inch, .830 inch, and .640 inch, respectively. Each of the flanges 124 and 126 includes a pin-containing portion 124a and 126a having six L-shaped pins embedded therein. The twelve pins are designated in the drawings P_1-P_{12}.

The bobbin 220 has a substantially rectangular-shaped tubular portion 222 having a core-receiving aperture 222a extending through it. Provided at opposite ends of the tubular portion 222 are first and second flanges 224 and 226. The wall thickness of each of the tubular portion 222 and the flanges 224 and 226 is about .040 inch. The width W_F and length L_F of each flange 224 and 226 are about 1.48 inches and 1.54 inches, respectively. The width W_A, height H_A and length L_A of the aperture 222a are about .765 inch, 1.02 inches, and .765 inch, respectively. Each of the flanges 224 and 226 includes a pin-containing portion 224a and 226a having six L-shaped pins embedded therein. The twelve pins are designated in the drawings P_1-P_{12}.

The first coil 140 of the transformer 100 is defined by first and second

primary winding portions 140a and 140b which are connected in series, see Fig. 8. The second coil 142 is defined by first and second secondary winding portions 142a and 142b which are connected in series.

A first wire 144, a type "39single-poly-nylon(SPN) 155°C" wire, is randomly wound in a clockwise direction about the tubular portion 122 to form the first primary winding portion 140a. The winding portion 140a comprises 500 turns and has a DC resistance of about 106 Ohms ± 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Figs. 8, 10, and 10A. A first layer 151 of a fiber reinforced polymeric film, such as the one discussed above with regard to the first embodiment of the present invention, is wrapped about the first primary winding portion 140a, see Fig. 11. The first layer 151 has a thickness of about .0065 inch.

A second wire 148, a type "32SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer 151 so as to form the first secondary winding portion 142a. The winding portion 142a comprises 1000 turns and has a DC resistance of about 46 Ohms ± 10%. It is soldered or otherwise connected to pins P_7 and P_9. A second layer 153 of the fiber reinforced polymeric film is wrapped about first secondary winding portion 142a, see Fig. 11. The second layer 153 has a thickness of about .0065 inch.

A third wire 150, a type "39SPN 155ºC" wire, is randomly wound in a clockwise direction about the second film layer 153 so as to form the second primary winding portion 140b. The wire 150 is soldered or otherwise connected to pin P_3, randomly wound about the second film layer 153 about 400 turns, and connected to pin P_5. In the illustrated embodiment, the third wire 150, after being connected to pin P_5, is randomly wound about the second film layer 153 another 100 turns and soldered or otherwise connected to pin P_6. In this embodiment, the winding portion 140b extends between pins P_3 and P_5, comprises 400 turns and has a DC resistance of about 107 Ohms ± 10%. A third layer 155 of the fiber reinforced polymeric film is wrapped about second primary winding portion 140b. The third layer 155 has a thickness of about .0065 inch. The first and second

primary winding portions 140a and 140b of the first transformer 100 are connected in series via pin P_3 so as to define the first coil 140 extending between pins P_1 and P_5.

A fourth wire 152, a type "34SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer 155 so as to form the second secondary winding portion 142b. The winding portion 142b comprises 1000 turns and has a DC resistance of about 58.0 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_9 and P_{11}. A fourth layer 157 of the fiber reinforced polymeric film is wrapped about second secondary winding portion 142b. The fourth layer 157 has a thickness of about .0065 inch. The first and second secondary winding portions 142a and 142b of the first transformer 100 are connected in series via pin P_9 so as to define the second coil 142 extending between pins P_7 and P_{11}.

The wires 144, 148, 150 and 152 are commercially available from the Phelps Dodge Corporation.

The core 130 of the first transformer is formed from numerous E-core and I-core sections 132 and 134, see Figs. 9 and 11, in substantially the same manner as described above with regard to core 30. The sections 132 and 143 comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the illustrated embodiment, each E-core section 132 has a thickness of about .014 inch. Each I-core section 134 has a thickness of about .014 inch. The length L_C of the core 130 is about 1.875 inches, the thickness T_C of the core 130 is about .625 inch, and the height H_C of the core 130 is about 1.5625 inches, see Fig. 9.

The primary winding portions 140a and 140b are interleaved with the secondary winding portions 142a and 142b so as to achieve a high degree of coupling between the primary winding portions 140a, 140b and the secondary winding portions 142a, 142b as well as to minimize the capacitance between the winding portions 140a, 140b and 142a, 142b. The transformer 100 is designed with very low flux density to increase the ability of the circuit 300 to accept low-level audio signals, increase primary inductance, decrease capacitive reactance and increase the overall frequency response of the circuit 300.

The first coil 240 of the second transformer 200 is defined by first and second primary winding portions 240a and 240b which are connected in series, see Fig. 8. The second coil 242 is defined by first and second secondary winding portions 242a and 242b which are connected in series.

A first wire 244, a type "39single-poly-nylon(SPN)155°C" wire, is randomly wound in a clockwise direction about the tubular portion 222 of the bobbin 220 to form the first primary winding portion 240a. The winding portion 240a comprises 1000 turns and has a DC resistance of about 250 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Figs. 8, 13 and 13A. A first layer 251 of a fiber reinforced polymeric film, such as the one used in the first embodiment described above, is wrapped about the first primary winding portion 240a. The first layer 251 has a thickness of about .0065 inch.

A second wire 248, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer 251 so as to form the first secondary winding portion 242a. The winding portion 242a comprises 2000 turns and has a DC resistance of about 156 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_7 and P_9. A second layer 253 of the fiber reinforced polymeric film is wrapped about first secondary winding portion 242a, see Fig. 14. The second layer has a thickness of about .0065 inch.

A third wire 250, a type "39SPN155°C" wire, is randomly wound in a clockwise direction about the second film layer 253 so as to form the second primary winding portion 240b. The wire 250 is soldered or otherwise connected to pin P_3, randomly wound about the second film layer 253 about 500 turns, and connected to pin P_5. In the illustrated embodiment, the third wire 250, after being connected to pin P_5, is randomly wound about the second film layer 253 another 500 turns and soldered or otherwise connected to pin P_6. In this embodiment, the winding portion 240b extends between pins P_3 and P_5, comprises 500 turns and has a DC resistance of about 150 Ohms $\pm$ 10%. A third layer 255 of the fiber reinforced polymeric film is wrapped about second primary winding portion 240b. The third layer 225 has a thickness of about .0065 inch. The first and second

primary winding portions 240a and 240b of the second transformer 200 are connected in series via pin P_3 so as to define the first coil 240 extending between pins P_1 and P_5.

A fourth wire 252, a type "34SPN155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer 255 so as to form the second secondary winding portion 242b. The winding portion 242b comprises 2000 turns and has a DC resistance of about 186 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_9 and P_{11}. A fourth layer 257 of the fiber reinforced polymeric film (not shown) is wrapped about the second secondary winding portion 242b. The fourth layer 257 has a thickness of about .0065 inch. The first and second secondary winding portions 242a and 242b of the second transformer 200 are connected in series via pin P_9 so as to define the second coil 242 extending between pins P_7 and P_{11}.

The wires 244, 248, 250 and 252 are commercially available from the Phelps Dodge Corporation.

The core 230 is formed from numerous E-core and I-core sections 232 and 234, see Figs. 12 and 14, in the same manner as core 30 described above. The sections 232 and 234 comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the illustrated embodiment, each E-core section 232 has a thickness of about .014 inch. Each I-core section 234 has a thickness of about .014 inch. The length L_C of the core 230 is about 2.25 inches, the thickness T_C of the core 230 is about .750 inch, and the height H_C of the core 230 is about 1.875 inches, see Fig. 1.

The primary winding portions 240a and 240b are interleaved with the secondary winding portions 242a and 242b so as to achieve a high degree of coupling between the primary winding portions 240a, 240b and the secondary winding portions 242a, 242b as well as to minimize the capacitance between the winding portions 240a, 240b and 242a, 242b. The transformer 200 is designed with very low flux density to increase the ability of the passive circuit 300 to accept low-level audio signals, increase primary inductance, decrease capacitive reactance

and increase the overall frequency response of the circuit 300.

The first and second transformers 100 and 200 are connected to one another in series, as illustrated in Fig. 8, to define the passive circuit 300. A first hook-up or jumper wire 301, a type 24 gauge (UL 1007) lead wire, is coupled to pin P_5 of the first transformer 100 and to pin P_5 of the second transformer 200 and a second hook-up wire 303, a type 24 gauge (UL 1007) lead wire, is coupled to pin P_7 of the second transformer 200 and pin P_7 of the first transformer 100. The 24 gauge lead wire is commercially available from Belden Corporation.

The input of the passive circuit 300 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 300 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 8. Any commercially available connector(s) may be used to connect the passive circuit 300 to the signal source including a single-ended connector or a balanced connector. No active element is connected between the source S and the audio amplifier A. It has been found that when the transformers 100 and 200 are used in this manner, they interact with one another such that when an input audio signal is transmitted through them, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 15, first, second and third exemplary frequency response curves C_1, C_2, C_3, generated by a passive circuit 300 constructed in accordance with the second embodiment described above, are shown. For each curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curves C_1, C_2, C_3 were obtained by connecting pins P_1 of the first and second transformers 100 and 200 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting pins P_{11} of the transformers 100 and 200 to resistive loads of 20 KOHMS (Curve C_1), 50 KOHMS (Curve C_2), and 100 KOHMS (Curve C_3), which loads represented equivalent impedances that the

transformers 100 and 200 might see when connected to conventional audio amplifiers. No active element was interposed between the input source S and the resistive loads.

Each of the first, second and third curves C_1, C_2, C_3 represents the amplification that occurs to frequency components of an input audio signal when the input audio signal passes through the passive circuit 300 and the output of the passive circuit 300 is connected to a resistive load. The resistive load is 20 KOHMS for curve C_1, 50 KOHMS for curve C_2, and 100 KOHMS for curve C_3. From these three curves C_1, C_2, C_3, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 300. This distortion is a non-linear amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 2.0 KHz for a 20 KOHMS load and between about 2.5 KHz and 3.5 KHz for 50 KOHMS and 100 KOHMS loads) to a peak high frequency (about 22 KHz for 20 KOHMS, 50 KOHMS and 100 KOHMS loads) and decrease in frequency from the intermediate frequency down to a peak low frequency (about 20 Hz for a 20 KOHMS load, about 800 Hz for a 50 KOHMS load and about 1000 Hz for a 100 KOHMS load). The amplification of the frequency components at the peak high frequency is from about 2.0 to about 3.4. The amplification of the frequency components at the peak low frequency is from about 1.9 to about 2.5. Hence, for Curve C_1, the amplification of the frequency component at the peak high frequency is about 1.8 times the amplification of the intermediate frequency component at 2 KHz and the amplification of the frequency component at the peak low_frequency is about 1.7 times the amplification of the intermediate frequency component at 2 KHz. For Curve C_2, the amplification of the frequency component at the peak high frequency is about 1.8 times the amplification of the intermediate frequency component at 3 KHz and the amplification of the frequency component at the peak low frequency is about

1.3 times the amplification of the intermediate frequency component at 3 KHz. For Curve C_3, the amplification of the frequency component at the peak high frequency is about 1.8 times the amplification of the intermediate frequency component at 3.5 KHz and the amplification of the frequency component at the peak low frequency is about 1.4 times the amplification of the intermediate frequency component at 3.5 KHz.

It is believed that the frequency response of the passive circuit 300 for a given load can be varied by changing one or more of the following: the number of turns of one or more of the coils 140, 142, 240, 242; the size and type of the wire used to make up one or more of the coils 140, 142, 240, 242; the DC resistance of one or more of the coils 140, 142, 240, 242; the shape and size of one or both of the cores 130 and 230; and the gauge and grade of the material used to form one or both of the cores 130 and 230. More specifically, the low end frequency response of the passive circuit 300 is controlled by factors such as: 1) the primary to secondary turns ratio (i.e., the ratio of the combined turns of the first coils 140 and 240 to the combined turns of the second coils 142 and 242); 2) the primary inductance which is controlled by the number of turns of the first and second coils 140, 142, 240, 242 and the gauge and grade of the material from which the cores 130 and 230 are made; 3) the DC resistance of the coils 140, 142, 240, 242, the size and type of wire used to make up the coils 140, 142, 240, 242, and the mean length of each turn of the coils 140, 142, 240, 242; and 4) the impedance of the signal source S and the load. The high end frequency response of the passive circuit 300 is controlled by factors such as: 1) the inter-windings capacitance, i.e., the capacitance between the first coils 140, 240 and the second coils 142 , 242; 2) the intra-windings capacitance, i.e., the capacitance between adjacent primary and secondary winding portions on each transformer 100 and 200; 3) primary and secondary winding portion placement; and 4) the impedance of the signal source S and the load.

It is also believed that if the capacitance of the transformer is varied, the amplification of the frequency components at the high end of the band of

frequencies may be varied. Capacitance may be altered by changing the thickness of one or more of the film layers 151, 153, 155, 251, 253, 255; the DC resistance of one or more of the winding portions 140a, 142a, 140b, 142b, 240a, 242a, 240b, 242b and/or the location of one or more of the winding portions 140a, 142a, 140b, 142b, 240a, 242a, 240b, 242b. It is further believed that if the inductance of one or both of the transformers 100 and 200 is varied, the amplification of the frequency components at the low end of the band of frequencies may be varied. Inductance can be altered by changing the combined turns of the first coils 140 and 240 and/or the gauge and grade of the material from which the cores 130 and 230 are made. Thus, an empirical evaluation is required to determine exactly the make up of the transformers 100 and 200 in order to effect a desired frequency response when the transformers 100 and 200 are coupled to a given load.

In accordance with a second embodiment of the present invention, an input audio signal is distorted into an enhanced audio signal by passing the input audio signal through a passive circuit 300 to amplify frequency components of the input signal. The amplification of the frequency components in the input audio signal increases as the frequency components increase in frequency from a first intermediate or reference frequency up to a peak high frequency and decrease in frequency from a second intermediate or reference frequency down to a peak low frequency. The first and second intermediate frequencies may be the same frequency or different frequencies. Above the peak high frequency, it may be desirable for the amplification to decrease as the frequency components increase in frequency from the peak high frequency to the high-end frequency. Below the peak low frequency, it may be desirable for the amplification to decrease as the frequency components decrease in frequency from the peak low frequency down to the low-end frequency.

It is further contemplated with regard to the second embodiment of the present invention that instead of each being a single frequency, it may be desirable for the peak high frequency, the peak low frequency or both to be a relatively

narrow range of frequencies such that frequency components falling within each narrow range have generally the same amplitude.

The peak high frequency may be in the range of from about 6 KHz to about 30 KHz. Amplification of the frequency component(s) at the peak high frequency may be from about 1.5 times to about 3.0 times the amplification of a first intermediate frequency. The peak low frequency may be in the range of from about 20 Hz to about 1 KHz. Amplification of the frequency component(s) at the peak low frequency may be from about 1.25 times to about 2.0 times the amplification of a second intermediate frequency.

It is further contemplated with regard to all embodiments of the present invention that one or more of the transformers may be tapped. Tapping may occur during the winding of any one of the first and second primary winding portions and the first and second secondary winding portions. After a predetermined number of turns of a winding portion have been wound about the bobbin but before the final number of turns have been formed, the wire being wound may be connected to another of the pins on the bobbin. In the illustrated embodiment, the first transformer is tapped. After the third wire 150 is randomly wound 400 times about the second film layer 153, it is wrapped or otherwise connected to pin P_5. Thereafter, the wire 150 is wound another 100 times and connected to pin P_6. If wire 301 is connected to pin P_5, the effective second primary winding portion 140b comprises 400 turns. Alternatively, if the wire 301 is connected to pin P_6, the effective second primary winding portion 140b comprises 500 turns. By changing the connection of the wire 301 from pin P_5 to pin P_6, the enhancement of the audio signal passing through the passive circuit 300 is changed.

Exemplary Embodiment No. 3

A passive circuit 800 comprising a first transformer 600 and first and second capacitors 900 and 902 (which capacitors are also referred to herein as first and second complex impedance circuits), constructed in accordance with a third

embodiment of the present invention, is illustrated in the circuit diagram of Fig. 16. The first transformer 600 is constructed in essentially the same manner as transformer 10 described above. It includes a bobbin 620, see Figs.17 and 18, a ferromagnetic core and first and second magnetically coupled coils 640 and 642, see Fig. 16. The first capacitor 900 is placed in series with the first coil 640 and the second capacitor 902 is placed in parallel with the second coil 642.

In the illustrated embodiment, the bobbin 620 is formed from a glass fiber reinforced nylon. One such bobbin is commercially available from Plastron Corporation under the product designation "0005A-34-90."

The bobbin 620 has a substantially rectangular-shaped tubular portion 622 having a core-receiving aperture 622a extending through it. Provided at opposite ends of the tubular portion 622 are first and second flanges 624 and 626. The wall thickness of each of the tubular portion 622 and the flanges 624 and 626 is about .037 inch. The width W_F and length L_F of flange 626 are about .720 inches and .937 inches, respectively. The width W_A, height H_A and length L_A of the aperture 622a are about .266 inch, .266 inch, and .476 inch, respectively. Flange 626 includes a pair of pin-containing portions each having three L-shaped pins embedded therein. The six pins are designated in the drawings P_1-P_6.

The first coil 640 of the transformer 600 is defined by first and second primary winding portions 640a and 640b which are connected in series, see Fig. 16. The second coil 642 is defined by first and second secondary winding portions 642a and 642b which are connected in series.

A first wire 644, a type "35single-poly-nylon(SPN) 155°C" wire, is randomly wound in a clockwise direction about the tubular portion 622 to form the first primary winding portion 640a. The winding portion 640a comprises 375 turns and has a DC resistance of about 21 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Fig. 16. A first layer of a fiber reinforced polymeric film is wrapped about the first primary winding portion 640a. Such a film is commercially available from TESA Inc. under the product designation "IL51596." The first film layer has a thickness of about .0045 inch.

A second wire 648, a type "39SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer so as to form the first secondary winding portion 642a. The winding portion 642a comprises 1125 turns and has a DC resistance of about 234 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_6 and P_5. A second layer of the IL51596 fiber reinforced polymeric film is wrapped about first secondary winding portion 642a. The second layer has a thickness of about .0045 inch.

A third wire 650, a type "35SPN 155ºC" wire, is randomly wound in a clockwise direction about the second film layer so as to form the second primary winding portion 640b. The winding portion 640b comprises 375 turns and has a DC resistance of about 33 Ohms $\pm$ 10%. The wire 650 is soldered or otherwise connected to pin P_3 and pin P_2. A third layer of the IL51596 fiber reinforced polymeric film is wrapped about second primary winding portion 640b. The third layer has a thickness of about .0045 inch. The first and second primary winding portions 640a and 640b of the first transformer 600 are connected in series via pin P_3 so as to define the first coil 640 extending between pins P_1 and P_2.

A fourth wire 652, a type "39SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer so as to form the second secondary winding portion 642b. The winding portion 642b comprises 1125.5 turns and has a DC resistance of about 311 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_5 and P_2. A fourth layer of the IL51596 fiber reinforced polymeric film is wrapped about second secondary winding portion 642b. The fourth layer has a thickness of about .0045 inch. The first and second secondary winding portions 642a and 642b of the first transformer 600 are connected in series via pin P_5 so as to define the second coil 642 extending between pins P_6 and P_2.

The wires 644, 648, 650 and 652 are commercially available from the Phelps Dodge Corporation.

The core of the first transformer is formed from numerous E-core and I-core sections, in substantially the same manner as described above with regard to

cores 30, 130 and 230. The E-core and I-core sections comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the described embodiment, each E-core section has a thickness of about .014 inch. Each I-core section has a thickness of about .014 inch. The length L_C of the core is about 1.0 inch, the thickness T_C of the core is about .25 inch, and the height H_C of the core is about .75 inch, when using the dimension designations illustrated in Fig. 1.

The primary winding portions 640a and 640b are interleaved with the secondary winding portions 642a and 642b so as to achieve a high degree of coupling between the primary winding portions 640a, 640b and the secondary winding portions 642a, 642b as well as to minimize the capacitance between the winding portions 640a, 640b and 642a, 642b.

The first capacitor 900 is connected in series with the first coil 640 of the first transformer 600 and the second capacitor 902 is connected in parallel with the second coil 642 of the first transformer 600 to define the passive circuit 800, see Fig. 16. In the illustrated embodiment, the capacitance of the first capacitor 900 is approximately 4.7 microfarads and the capacitance of the second capacitor 902 is approximately .001 microfarads. These capacitance values may be varied as will be discussed below.

The input of the passive circuit 800 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 800 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 16.

Any commercially available connector(s) may be used to connect the passive circuit 800 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 800 is coupled in this manner and an input audio signal made up of frequency components within a

band of frequencies having a low end and a high end is transmitted through the circuit 800, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 19, an exemplary frequency response curve C_1 generated by a passive circuit 800 constructed in accordance with the third embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_1 was obtained by connecting the input of the circuit 800 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 800 to a resistive load of 100 KOHMS, which load represented an equivalent impedance that the circuit 800 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_1, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 800. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 3 KHz for the 100 KOHMS load) to a peak high frequency (about 20 KHz for the 100 KOHMS load) and decrease in frequency from the intermediate frequency down to a peak low frequency (about 50 Hz for a 100 KOHMS load). The amplification of the frequency components at the peak high frequency is from about 1.5 to about 3.5 and preferably about 1.65. The amplification of the frequency components at the peak low frequency is from about 1.25 to about 3.0 and preferably about 1.5. Hence, for curve C_1, the amplification of the frequency component at the peak high frequency is about 1.65 times the amplification of the intermediate frequency component at 3 KHz and the

amplification of the frequency component at the peak low frequency is about 1.5 times the amplification of the intermediate frequency component at 3 KHz.

By changing the capacitance of the second capacitor 902, the location of the peak high frequency (i.e., the peak high resonant frequency) along the frequency axis, can by varied. Similarly, by changing the capacitance of the first capacitor 900, the location of the peak low frequency (i.e., the peak low resonant frequency) along the frequency axis, can be varied. More specifically, once the coil inductance is known, the following equation can be used to determine a required capacitance to achieve a desired (peak high or low) resonant frequency for either the first coil 640 or the second coil 642:

$$\text{Frequency}_{\text{resonant}} = 1 / (2)(\pi)(\text{square root } (LC))$$

wherein $\pi = 3.14159$;

L = inductance; and

C = capacitance.

The amplitude at the peak low frequency can be varied by changing the resistance, inductance and/or capacitance of the first coil 640. The amplitude at the peak high frequency can be varied by changing the resistance, inductance and/or capacitance of the second coil 642.

First and second passive circuits 800a and 800b, each of which is equivalent to the passive circuit 800 illustrated in Fig. 16, may be provided within a single housing 2000a of a cable/passive circuit assembly 2000b, see Figs. 19A and 19B, thereby defining a two channel audio signal enhancement device. A bypass switch 2002a (a conventional double-throw switch) is also provided in the housing 2000. When the switch 2002a is in a first, non-bypass position, the first passive circuit 800a receives an input audio signal from a first audio signal source S_1 via a conductor (e.g., a wire) 2001a which may be incorporated within a cable 2003a

and outputs an enhanced audio signal to a first audio amplifier A_1 via a conductor (e.g. a wire) 2001b which may be incorporated within a cable 2003b and the second passive circuit 800b receives an input audio signal from a second audio signal source S_2 via a conductor (e.g. a wire) 2001c which may be incorporated within the cable 2003a and outputs an enhanced audio signal to a second audio amplifier A_2 via a conductor (e.g. a wire) 2001d which may be incorporated within the cable 2003b. Referring to Fig. 19B, when the switch 2002a is in its first position, pin 2 is coupled to pin 3, pin 8 is coupled to pin 9, pin 5 is coupled to pin 6 and pin 11 is coupled to pin 12. Hence, the input signal from S_1 passes through pins 1, 9, and 8 to the circuit 800a and the enhanced audio signal passes from the circuit 800a to the first audio amplifier A_1 via pins 3 and 2. Also, the input signal from S_2 passes through pins 4, 12, and 11 to the circuit 800b and the enhanced audio signal passes from the circuit 800b to the second audio amplifier A_2 via pins 6 and 5.

When the switch 2002a is in a second, bypass position, the signal from the first audio signal source S_1 bypasses the first circuit 800a and is provided directly to the first audio amplifier A_1 and the signal from the second audio source S_2 bypasses the second circuit 800b and is provided directly to the second audio amplifier A_2. Referring to Fig. 19B, when the switch 2002a is in its second position, pin 2 is coupled to pin 1, pin 8 is coupled to pin 7, pin 5 is coupled to pin 4 and pin 11 is coupled to pin 10. Hence, the input signal from signal source S_1 passes through pins 1 and 2 to the first audio amplifier A_1 and the input signal from signal source S_2 passes through pins 4 and 5 to the second audio amplifier A_2.

It is also contemplated that the cable/passive circuit assembly 2000b may be constructed without a bypass switch such that the input audio signals from the first and second signal sources always pass through the first and second passive circuits 800a and 800b. It is further contemplated that the cable/passive circuit assembly may be constructed as a single channel device so that it includes only a single passive circuit within its housing. Hence, only a single audio signal from one signal source would be provided to the cable/passive circuit assembly. The single

channel cable/passive circuit assembly may be provided with or without a bypass switch.

It is also contemplated that passive circuit 5, passive circuit 300, or the transformer illustrated in Fig. 7D may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

Exemplary Embodiment No. 4

A passive circuit 1000 comprising a transformer 1100 and first and second capacitors 1200 and 1202 (which capacitors are also referred to herein as first and second complex impedance circuits), constructed in accordance with a fourth embodiment of the present invention, is illustrated in the circuit diagram of Fig. 20. The transformer 1100 includes a bobbin 1120, see Figs. 21 and 22, a ferromagnetic core and first and second magnetically coupled coils 1140 and 1142, see Fig. 20. The first capacitor 1200 is placed in series with the first coil 1140 and the second capacitor 1202 is placed in parallel with the second coil 1142.

In the illustrated embodiment, the bobbin 1120 is formed from a glass fiber reinforced nylon. One such bobbin is commercially available from Plastron Corporation under the product designation "0938B-31-80."

The bobbin 1120 has a substantially rectangular-shaped tubular portion 1122 having a core-receiving aperture 1122a extending through it. Provided at opposite ends of the tubular portion 1122 are first and second flanges, only flange 1124 is shown in Fig. 22. The wall thickness of the tubular portion 1122 is about .04 inch and the wall thickness of each of the flanges is about .030 inch. The width W_A, height H_A and length L_A of the aperture 1122a are about .200 inch, .200 inch, and .370 inch, respectively. Each of the flanges includes a pin-containing portion coupled to it having four L-shaped pins embedded therein. The eight pins are designated in the drawings P_1-P_8.

The first coil 1140 of the transformer 1100 is defined by a primary winding portion 1140a, see Fig. 16. The second coil 1142 is defined by a secondary

winding portion 1142a.

A first wire 1144, a type "38single-poly-nylon(SPN) 155°C" wire, is randomly wound in a clockwise direction about the tubular portion 1122 to form the primary winding portion 1140a. The winding portion 1140a comprises 400 turns and has a DC resistance of about 25 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_1 and P_3, see Fig. 20. A first layer of a fiber reinforced polymeric film is wrapped about the primary winding portion 1140a. Such a film is commercially available from TESA Inc. under the product designation "IL51587." The first film layer has a thickness of about .0045 inch.

A second wire 1148, a type "37SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer so as to form the secondary winding portion 1142a. The winding portion 1142a comprises 950 turns and has a DC resistance of about 66 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_5 and P_8. A second layer of the IL51587 fiber reinforced polymeric film is wrapped about the secondary winding portion 1142a. The second layer has a thickness of about .0045 inch.

The wires 1144 and 1148 are commercially available from the Phelps Dodge Corporation.

The core of the first transformer is formed from numerous E-core and I-core sections, in substantially the same manner as described above with regard to cores 30, 130 and 230. The E-core and I-core sections comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the described embodiment, each E-core section has a thickness of about .014 inch. Each I-core section has a thickness of about .014 inch. The length L_C of the core is about .75 inch, the thickness T_C of the core is about .187 inch, and the height H_C of the core is about .625 inch, when using the dimension designations illustrated in Fig. 1.

The first capacitor 1200 is connected in series with the first coil 1140 of the transformer 1100 and the second capacitor 1202 is connected in parallel with the second coil 1142 of the transformer 1100 to define the passive circuit 1000, see Fig. 20. In the illustrated embodiment, the capacitance of the first capacitor

1200 is approximately 12.0 microfarads and the capacitance of the second capacitor 1202 is approximately .0082 microfarads. These capacitance values may be varied. In particular, by changing the capacitance of the capacitor 1202, the location of the peak high frequency along the frequency axis can be varied. By changing the capacitance of the capacitor 1200, the location of the peak low frequency along the frequency axis can be changed.

The input of the passive circuit 1000 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 1000 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 20.

Any commercially available connector(s) may be used to connect the passive circuit 1000 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 1000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the circuit 1000, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 23, an exemplary frequency response curve C_2 generated by a passive circuit 1000 constructed in accordance with the fourth embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_2 was obtained by connecting the input of the circuit 1000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 1000 to a resistive load of 100 KOHMS, which load represented an

equivalent impedance that the circuit 1000 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_2, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 1000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 3 KHz for the 100 KOHMS load) to a peak high frequency (about 20 KHz for the 100 KOHMS load) and decrease in frequency from the intermediate frequency down to a peak low frequency (about 50 Hz for a 100 KOHMS load). The amplification of the frequency components at the peak high frequency is from about 1.2 to about 3.0 and preferably about 1.4 . The amplification of the frequency components at the peak low frequency is from about 1.2 to about 3.0 and preferably about 1.4. Hence, for curve C_2, the amplification of the frequency component at the peak high frequency is about 1.4 times the amplification of the intermediate frequency component at 3 KHz and the amplification of the frequency component at the peak low frequency is about 1.4 times the amplification of the intermediate frequency component at 3 KHz.

It is also contemplated that passive circuit 1000 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

<u>Exemplary Embodiment No. 5</u>

A passive circuit 2000 comprising a transformer 2002, and first and second capacitors 2004 and 2006 (which capacitors are also referred to herein as first and second complex impedance circuits), constructed in accordance with a fifth embodiment of the present invention, is illustrated in the circuit diagram of Fig.

24. The transformer 2002 is constructed in essentially the same manner as transformer 10 described above. It includes a bobbin, a ferromagnetic core and first and second magnetically coupled coils 2020 and 2022, see Fig. 24. The first capacitor 2004 is placed in series with the first coil 2020 and the second capacitor 2006 is placed in parallel with the second coil 2022.

The bobbin used in transformer 2002 may comprise bobbin 620 illustrated in Figs. 17 and 18. Such a bobbin is commercially available from Plastron Corporation under the product designation "0005A-34-90."

The first coil 2020 of the transformer 2002 is defined by first and second primary winding portions 2020a and 2020b which are connected in series, see Fig. 24. The second coil 2022 is defined by first and second secondary winding portions 2022a and 2022b which are connected in series.

A first wire 2024, a type "37single-poly-nylon(SPN) 155°C" wire, is randomly wound in a clockwise direction about the bobbin tubular portion 622 to form the first primary winding portion 2020a. The winding portion 2020a comprises 625 turns and has a DC resistance of about 39.8 Ohms ± 10%. It is soldered or otherwise connected to pins P_1 and P_2, see Fig. 24. A first layer of a fiber reinforced polymeric film is wrapped about the first primary winding portion 2020a. Such a film is commercially available from TESA Inc. under the product designation "IL51596." The first film layer has a thickness of about .0045 inch.

A second wire 2026, a type "42SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer so as to form the first secondary winding portion 2022a. The winding portion 2022a comprises 1640 turns and has a DC resistance of about 404 Ohms ± 10%. It is soldered or otherwise connected to pins P_6 and P_5. A second layer of the IL51596 fiber reinforced polymeric film is wrapped about first secondary winding portion 2022a. The second layer has a thickness of about .0045 inch.

A third wire 2028, a type "37SPN 155°C" wire, is randomly wound in a clockwise direction about the second film layer so as to form the second primary winding portion 2020b. The winding portion 2020b comprises 625 turns and has a

DC resistance of about 56 Ohms ± 10%. The wire 2028 is soldered or otherwise connected to pin P_2 and pin P_3. A third layer of the IL51596 fiber reinforced polymeric film is wrapped about second primary winding portion 2020b. The third layer has a thickness of about .0045 inch. The first and second primary winding portions 2020a and 2020b of the transformer 2002 are connected in series via pin P_2 so as to define the first coil 2020 extending between pins P_1 and P_3. The first coil 2020 has an internal resistance of about 95.8 Ohms ± 1%.

A fourth wire 2030, a type "42SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer so as to form the second secondary winding portion 2022b. The winding portion 2022b comprises 1640 turns and has a DC resistance of about 540 Ohms ± 10%. It is soldered or otherwise connected to pins P_5 and P_4. A fourth layer of the IL51596 fiber reinforced polymeric film is wrapped about second secondary winding portion 2022b. The fourth layer has a thickness of about .0045 inch. The first and second secondary winding portions 2022a and 2022b of the transformer 2002 are connected in series via pin P_5 so as to define the second coil 2022 extending between pins P_4 and P_6. The second coil 2022 has an internal resistance of about 944 Ohms ± 1%.

The wires 2024, 2026, 2028 and 2030 are commercially available from the Phelps Dodge Corporation.

The core of the first transformer is formed from numerous E-core and I-core sections, in substantially the same manner as described above with regard to cores 30, 130 and 230. The E-core and I-core sections comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the described embodiment, each E-core section has a thickness of about .014 inch. Each I-core section has a thickness of about .014 inch. The length L_C of the core is about 1.0 inch, the thickness T_C of the core is from about .056 inch to about .25 inch, and the height H_C of the core is about .75 inch, when using the dimension designations illustrated in Fig. 1.

The primary winding portions 2020a and 2020b are interleaved with the

secondary winding portions 2022a and 2022b so as to achieve a high degree of coupling between the primary winding portions 2020a, 2020b and the secondary winding portions 2022a, 2022b as well as to minimize the capacitance between the winding portions 2020a, 2020b and 2022a, 2022b.

The first capacitor 2004 is connected in series with the first coil 2020 of the transformer 2002 and the second capacitor 2006 is connected in parallel with the second coil 2022 of the transformer 2002 to define the passive circuit 2000, see Fig. 24. In the illustrated embodiment, the capacitance of the first capacitor 2004 is approximately 39 microfarads and the capacitance of the second capacitor 2006 is approximately .0018 microfarads. These capacitance values may be varied as will be discussed below.

The input of the passive circuit 2000 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 2000 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 24.

Any commercially available connector(s) may be used to connect the passive circuit 2000 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 2000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the circuit 2000, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 25, an exemplary frequency response curve C_5 generated by a passive circuit 2000 constructed in accordance with the fifth embodiment described above, is shown. For this curve, output voltages are plotted versus

frequency for normalized input signals. The frequency response curve C_5 was obtained by connecting the input of the circuit 2000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 2000 to a resistive load of 10 KOHMS, which load represented an equivalent impedance that the circuit 2000 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_5, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 2000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from a first intermediate frequency (about 3.0 KHz for the 10 KOHMS load) to a peak high frequency (about 20.0 KHz for the 10 KOHMS load) and decrease in frequency from a second intermediate frequency (about 500 Hz for the 10 KOHMS load) down to a peak low frequency (about 50 Hz for the 10 KOHMS load). The amplification of the frequency components at or in the vicinity of the peak high frequency is from about 1.25 to about 6.0 and preferably about 3.55. The amplification of the frequency components at or in the vicinity of the peak low frequency is from about 1.1 to about 3.0 and preferably about 2.70. Hence, for curve C_5, the amplification of the frequency component at the peak high frequency is about 1.5 times the amplification of the first intermediate frequency component at 3.0 KHz and the amplification of the frequency component at the peak low frequency is about 1.15 times the amplification of the second intermediate frequency component at 500 Hz.

By changing the capacitance of the second capacitor 2006, the location of the peak high frequency (i.e., the peak high resonant frequency) along the frequency axis, can by varied. Similarly, by changing the capacitance of the first

capacitor 2004, the location of the peak low frequency (i.e., the peak low resonant frequency) along the frequency axis, can be varied. More specifically, once the inductance of either the first coil 2020 or the second coil 2022 is known, the following equation can be used to determine a required capacitance to achieve a desired (peak high or peak low) resonant frequency for either the first coil 2020 or the second coil 2022:

$$\text{Frequency}_{\text{resonant}} = 1 / (2)(\pi)(\text{square root }(LC))$$

wherein $\pi = 3.14159$;

L = inductance for either the first coil or the second coil; and

C = capacitance of capacitor 2004 when the inductance of the first coil 2020 is provided and capacitor 2006 when the inductance of the second coil 2022 is provided.

The amplitude at the peak low frequency can be varied by changing the resistance, inductance and/or capacitance of the first coil 2020. The amplitude at the peak high frequency can be varied by changing the resistance, inductance and/or capacitance of the second coil 2022.

It is also contemplated that passive circuit 2000 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

<u>Exemplary Embodiment No. 6</u>

A passive circuit 3000 comprising a transformer 3002 and first and second complex impedance circuits 3010 and 3020, constructed in accordance with a sixth embodiment of the present invention, is illustrated in the circuit diagram of Fig. 26. The transformer 3002 comprises first and second magnetically coupled coils 3002a and 3002b. It may be constructed in the same manner and from the

same elements as transformer 2002, schematically illustrated in Fig. 24 and discussed supra. The first complex impedance circuit 3010 comprises a twin-T network 3010a. It is provided in cascade with the first coil 3002a and defines in combination with the transformer 3002 a location of a peak low frequency f_{PL} of a frequency response curve C_6, illustrated in Fig. 27 and generated for the passive circuit 3000. The second complex impedance circuit 3020 comprises a single capacitor 3022 having a capacitance of about .0015 microfarads. It is provided in parallel with the second coil 3002b, and defines with the second coil 3002b the location of a peak high frequency f_{PH} of the frequency response curve C_6.

The twin-T network 3010a comprises capacitors 3012, 3013 and 3014, each having a capacitance of approximately 2.2 microfarads. It also comprises first and second resistors 3015 and 3016, each having a resistance of about 30 Ohms and a third resistor 3017 having a resistance of about 100,000 Ohms.

The capacitance and resistance values of the capacitors and resistors in the first and second complex impedance circuits 3010 and 3020 may be varied as discussed below.

The input of the passive circuit 3000 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 3000 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 26.

Any commercially available connector(s) may be used to connect the passive circuit 3000 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 3000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the circuit 3000, the audio signal is distorted into an enhanced audio signal that

exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 27, an exemplary frequency response curve C_6 generated by a passive circuit 3000 constructed in accordance with the sixth embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_6 was obtained by connecting the input of the circuit 3000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 3000 to a resistive load of 10 KOHMS, which load represented an equivalent impedance that the circuit 3000 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_6, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 3000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 3.5 KHz for the 10 KOHMS load) to a peak high frequency (about 16.5 KHz for the 10 KOHMS load) and decreases in frequency from the intermediate frequency down to a peak low frequency (about 250 Hz for a 10 KOHMS load). The amplification of the frequency components at or near the peak high frequency is from about 1.25 to about 6.0 and preferably about 2.75. The amplification of the frequency components at or near the peak low frequency is from about 1.1 to about 3.0 and preferably about 2.2. Hence, for curve C_6, the amplification of the frequency component at the peak high frequency is about 2.75 times the amplification of the intermediate frequency component at 3.5 KHz and the amplification of the frequency component at the peak low frequency is about 2.2 times the amplification of the intermediate frequency component at 3.5 KHz.

It is also contemplated that passive circuit 3000 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

In designing the passive circuit 3000, which includes a twin-T network in cascade with the first or primary coil 3002a of the transformer 3002, the inventors used a passive circuit model 3100, illustrated in Fig. 28, as a starting point in the design process. The model 3100 comprises a twin-T network TTC, a transformer 3102 and a capacitor 3122. The transformer 3102 includes first and second magnetically coupled coils 3102a and 3102b and may be constructed in the same manner and from the same elements as transformer 2002, schematically illustrated in Fig. 24 and discussed supra. The capacitor 3122 is provided in parallel with the second coil 3102b, and defines with the second coil 3102b the location of a peak high frequency point on a frequency response C_M curve, an example of which is illustrated in Fig. 29. The twin-T network TTC comprises first and second capacitors 3112 and 3113, each having a capacitance value of C, and a third capacitor 3114 having a capacitance value of 2C. The twin-T network TTC further comprises first and second resistors 3115 and 3116, each having a resistance value of R, and a third resistor 3117, having a resistance value of R/2. When capacitors 3112, 3113 have a capacitance equal to C, capacitor 3114 has a capacitance equal to 2C, resistors 3115 and 3116 have a resistance equal to R and resistor 3117 has a resistance equal to R/2, the location of a reference or resonant frequency (i.e., the frequency of a lowest point on the frequency response curve between a point at the peak high frequency f_{PH} and a point at the peak low frequency f_{PL}), labeled f_R in Fig. 29, is defined by the following equation:

$$F_R = 1/((2)(\pi)(R)(C))$$

where F_R = reference or resonant frequency; and

$\pi = 3.1423$;

R = resistance value defined above; and

C = capacitance value defined above.

As is apparent from Fig. 29, a point on the frequency response curve C_M at the reference frequency F_R for a circuit constructed in accordance with model circuit 3100 has an amplitude of 0 volts. Further, a width W_N of a notch portion N (i.e., the portion of the frequency response curve C_M between the peak low frequency f_{PL} and the peak high frequency f_{PH}) is narrowest when capacitors 3112, 3113 have a capacitance equal to C, capacitor 3114 has a capacitance equal to 2C, resistors 3115 and 3116 have a resistance equal to R and resistor 3117 has a resistance equal to R/2.

As noted above, in designing the passive circuit 3000, the inventors used the above model circuit 3100 as a starting point. More specifically, they made modifications to the values of the capacitors and resistors of the twin-T network TTC as well as the value of the capacitor 3122 until a desired frequency response was achieved. The following general rules were used when the model circuit 3100 was modified:

1) By increasing the resistances of resistors 3115 and 3116 and/or the resistance of the first coil 3102a, the amplitudes of points on the frequency response curve at a peak low frequency f_{PL} and a peak high frequency f_{PH} can be lowered. By decreasing the resistances of resistors 3115 and 3116 and/or the resistance of the first coil 3102a, the amplitudes of the points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be increased.

2) The amplitude of the point on the frequency response curve at the peak high frequency can be increased by increasing the capacitance of the capacitors 3112 and 3113 and/or decreasing the resistance of the second coil 3102b. The amplitude of the point on the frequency response curve at the peak high frequency can be decreased by doing one or more of the following: decreasing the

capacitance of the capacitors 3112 and 3113; increasing the resistance of the second coil 3102b; and/or adding a resistor (not shown) in series with the second coil 3102b.

3) By increasing the capacitance value of any one of the capacitors 3112, 3113, 3114 and/or by increasing the resistance value of any one of the resistors 3115, 3116 and 3117, the location of a point on the frequency response curve at the reference frequency f_R can be shifted to the left, i.e., towards 0 Hz, and by decreasing the capacitance value of any one of the capacitors 3112, 3113, 3114 and/or by decreasing the resistance value of any one of the resistors 3115, 3116 and 3117, the location of the point on the frequency response curve at the reference frequency f_R can be shifted to the right.

4) The amplitude of the point on the frequency response curve at the reference frequency f_R and the width W_N of the notch portion N of the curve can be varied by increasing or decreasing the capacitance value of capacitor 3114 relative to the capacitance values of capacitors 3112 and 3113 and/or by increasing or decreasing the resistance value of resistor 3117 relative to the resistance values of resistors 3115 and 3116.

5) The location of the peak high frequency f_{PH} can be moved to the left toward 0 Hz by increasing the capacitance value of capacitor 3122 and to the right by decreasing the capacitance value of the capacitor 3122.

6) The frequency position of the reference frequency f_R and the width W_N of the notch N sets the position of the peak low frequency f_{PL} as a by-product.

<u>Exemplary Embodiment No. 7</u>

A passive circuit 4000 comprising a transformer 4010 and first and second complex impedance circuits 4020 and 4030, constructed in accordance with an seventh embodiment of the present invention, is illustrated in the circuit diagram of Fig. 30. The transformer 4010 comprises first and second magnetically coupled coils 4010a and 4010b. It may be constructed in the same manner and from the same elements as transformer 2002, schematically illustrated in Fig. 24 and

discussed supra. The first complex impedance circuit 4020 comprises a bridged-T network 4020a. It is provided in cascade with the first coil 4010a and defines with the transformer 4010 a location of a peak low frequency f_{PL} of a frequency response curve C_7, illustrated in Fig. 30, generated for the passive circuit 4000. The second complex impedance circuit 4030 comprises a single capacitor 4032 having a capacitance of about .0015 microfarads. It is provided in parallel with the second coil 4010b, and defines with the second coil 4010b the location of a peak high frequency f_{PH} of the frequency response curve C_7.

The bridged-T network 4020a comprises capacitors 4022 and 4024, each having a capacitance of approximately 1.5 microfarads. It also comprises a first resistor 4026 having a resistance of about 25 Ohms and a second resistor 4028 having a resistance of about 25 Ohms.

The capacitance and resistance values of the first and second complex impedance circuits 4020 and 4030 may be varied so as to alter the frequency response of the circuit 4000. In particular, the location of the peak high frequency f_{PH} of the frequency response curve along the frequency axis can be varied by changing the capacitance value of capacitor 4032.

The input of the passive circuit 4000 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 4000 may be coupled directly to an audio amplifier A, such as a pre-amplifier stage or a power amplifier stage, see Fig. 30.

Any commercially available connector(s) may be used to connect the passive circuit 4000 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 4000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the

circuit 4000, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 31, an exemplary frequency response curve C_7 generated by a passive circuit 4000 constructed in accordance with the seventh embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_7 was obtained by connecting the input of the circuit 4000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 4000 to a resistive load of 10 KOHMS, which load represented an equivalent impedance that the circuit 4000 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_7, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 4000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate or reference frequency f_R (about 3.0 KHz for the 10 KOHMS load) to a peak high frequency (about 16.0 KHz for the 10 KOHMS load) and decrease in frequency from the intermediate frequency down to a peak low frequency (about 250 Hz for a 10 KOHMS load). The amplification of the frequency components at or near the peak high frequency is from about 1.25 to about 6.0 and preferably about 2.8. The amplification of the frequency components at or near the peak low frequency is from about 1.1 to about 3.0 and preferably about 2.5. Hence, for curve C_7, the amplification of the frequency component at the peak high frequency is about 2.8 times the amplification of the intermediate frequency component at 3.0 KHz and the amplification of the frequency component at the

peak low frequency is about 2.1 times the amplification of the intermediate frequency component at 3.0 KHz.

It is also contemplated that passive circuit 4000 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

Exemplary Embodiment No. 8

A passive circuit 5000 comprising a transformer 5010 and first and second complex impedance circuits 5020 and 5030, constructed in accordance with an eighth embodiment of the present invention, is illustrated in the circuit diagram of Fig. 32. The transformer 5010 comprises first and second magnetically coupled coils 5010a and 5010b. It may be constructed in the same manner and from the same elements as transformer 2002, schematically illustrated in Fig. 24 and discussed supra. The first complex impedance circuit 5020 comprises a resistor 5022, a capacitor 5024 and an inductor 5026, all provided in parallel with one another and which define a parallel resonant circuit. The resistor 5022 has a resistance of about 2000 Ohms, the capacitor 5024 has a capacitance of about .047 microfarads and the inductor 5026 has an inductance of about 33 millihenrys. The circuit 5020 is provided in series with the first coil 5010a and defines with the transformer 5010 a location of a peak low frequency f_{PL} of a frequency response curve C_8, illustrated in Fig. 33, generated for the passive circuit 5000. The second complex impedance circuit 5030 comprises a single capacitor 5030a having a capacitance of about .0022 microfarads. It is provided in parallel with the second coil 5010b, and defines with the second coil 5010b the location of a peak high frequency f_{PH} of the frequency response curve C_8.

The capacitance, inductance and resistance values of the first and second circuits 5020 and 5030 may be varied so as to alter the frequency response of the circuit 5000. In particular, if the value of the capacitor 5024 and/or the value of the inductor 5026 is varied, the location along the frequency axis of an

intermediate or reference frequency f_R of the response curve C_8 can be changed. If the value of the resistor 5022 is varied, the amplitude of a point on the curve C_8 at the reference frequency f_R and the width W of the notch N can be changed. If the value of the capacitor 5030a is altered, the location along the frequency axis of a peak high frequency f_{PH} of the response curve C_8 can be changed. By increasing the resistance of the first coil 5010a, the amplitudes of points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be lowered. By decreasing the resistance of the first coil 5010a, the amplitudes of points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be increased. By decreasing the resistance of the second coil 5010b, the amplitude of the point on the frequency response curve at the peak high frequency can be increased. The amplitude of the point on the frequency response curve at the peak high frequency can be decreased by increasing the resistance of the second coil 5010b, and/or adding a resistor (not shown) in series with the second coil 5010b. The frequency position of the reference frequency f_R and the width W of the notch N sets the position of the peak low frequency f_{PL} as a by-product.

The input of the passive circuit 5000 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 5000 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 32.

Any commercially available connector(s) may be used to connect the passive circuit 5000 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 5000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the

circuit 5000, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 33, an exemplary frequency response curve C_8 generated by a passive circuit 5000 constructed in accordance with the eighth embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_8 was obtained by connecting the input of the circuit 5000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 5000 to a resistive load of 10 KOHMS, which load represented an equivalent impedance that the circuit 5000 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_8, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 5000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 4.0 KHz for the 10 KOHMS load) to a peak high frequency (about 16.0 KHz for the 10 KOHMS load) and decreases in frequency from the intermediate frequency down to a range of peak low frequencies (from about 100 Hz to about 1000 Hz for a 10 KOHMS load). The amplification of the frequency component at the peak high frequency is from about 1.25 to about 6.0 and preferably about 3.2. The amplification of the frequency components within the peak low frequency range is from about 1.1 to about 3.0 and preferably about 2.1. Hence, for curve C_8, the amplification of the frequency component at the peak high frequency is about 3.1 times the amplification of the intermediate frequency component at 4.0 KHz and the amplification of the frequency

components within the peak low frequency range is about 2.1 times the amplification of the intermediate frequency component at 4.0 KHz.

It is also contemplated that passive circuit 5000 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

Exemplary Embodiment No. 9

A passive circuit 6000 comprising a transformer 6010 and first and second complex impedance circuits 6020 and 6030, constructed in accordance with an ninth embodiment of the present invention, is illustrated in the circuit diagram of Fig. 34. The transformer 6010 comprises first and second magnetically coupled coils 6010a and 6010b. It may be constructed in the same manner and from the same elements as transformer 2002, schematically illustrated in Fig. 24 and discussed supra. The first complex impedance circuit 6020 comprises a resistor 6022, a capacitor 6024 and an inductor 6026, all in parallel with one another, and which define a parallel resonant circuit. The resistor 6022 has a resistance of about 12,500 Ohms, the capacitor 6024 has a capacitance of about .0056 microfarads and the inductor 6026 has an inductance of about .25 henrys. The first circuit 6020 is provided in cascade with the second coil 6010b and the second complex impedance circuit 6030. The second complex impedance circuit 6030 comprises a single capacitor 6030a having a capacitance of about .0018 microfarads. It is provided in parallel with the second coil 6010b, and defines with the second coil 6010b the location of a peak high frequency f_{PH} of a frequency response curve C_9, see Fig. 35.

The capacitance, inductance and resistance values of the first and second circuits 6020 and 6030 may be varied so as to alter the frequency response of the circuit 6000. More specifically, if the value of the capacitor 6024 and/or the value of the inductor 6026 is varied, the location along the frequency axis of an intermediate or reference frequency f_R of the response curve C_9 can be changed. If

the value of the resistor 6022 is varied, the amplitude of a point on the frequency response curve C_9 at the reference frequency f_R and the width W_9 of a notch portion N_9 of the frequency response curve C_9 can be changed. If the value of the capacitor 6030a is altered, the location along the frequency axis of a peak high frequency f_{PH} of the response curve C_9 can be changed. If the resistive values of resistor 6022, the first coil 6010a and/or the amplifier A are changed, the location along the frequency axis of a peak low frequency f_{PL} of the response curve C_9 can be changed. By increasing the resistance of the first coil 6010a, the amplitudes of points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be lowered. By decreasing the resistance of the first coil 6010a, the amplitudes of points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be increased. By decreasing the resistance of the second coil 6010b, the amplitude of the point on the frequency response curve at the peak high frequency can be increased. The amplitude of the point on the frequency response curve at the peak high frequency can be decreased by increasing the resistance of the second coil 6010b, and/or adding a resistor (not shown) in series with the second coil 6010b.

The input of the passive circuit 6000 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 6000 may be coupled directly to an audio amplifier A, such as a pre-amplifier stage or a power amplifier stage, see Fig. 34.

Any commercially available connector(s) may be used to connect the passive circuit 6000 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 6000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the

circuit 6000, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 35, an exemplary frequency response curve C_9 generated by a passive circuit 6000 constructed in accordance with the ninth embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_9 was obtained by connecting the input of the circuit 6000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 6000 to a resistive load of 10 KOHMS, which load represented an equivalent impedance that the circuit 6000 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_9, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 6000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 4.0 KHz for the 10 KOHMS load) to a peak high frequency (about 16.0 KHz for the 10 KOHMS load) and decrease in frequency from the intermediate frequency down to a range of peak low frequencies (about 100 Hz to about 1000 Hz for a 10 KOHMS load). The amplification of the frequency component at the peak high frequency is from about 1.25 to about 6.0 and preferably about 3.2. The amplification of the frequency components within the peak low frequency range is from about 1.1 to about 3.0 and preferably about 2.2. Hence, for curve C_9, the amplification of the frequency component at the peak high frequency is about 3.2 times the amplification of the intermediate frequency component at 4.0 KHz and the amplification of the frequency

components within the peak low frequency range is about 2.2 times the amplification of the intermediate frequency component at 4.0 KHz.

It is also contemplated that passive circuit 6000 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

Exemplary Embodiment No. 10

A passive circuit 6050 comprising a transformer 6060 and first and second complex impedance circuits 6070 and 6080, constructed in accordance with a tenth embodiment of the present invention, is illustrated in the circuit diagram of Fig. 36. The transformer 6060 comprises first and second magnetically coupled coils 6060a and 6060b. It may be constructed in the same manner and from the same elements as transformer 2002, schematically illustrated in Fig. 24 and discussed supra. The first complex impedance circuit 6070 comprises a resistor 6072, a capacitor 6074 and an inductor 6076, all in parallel with one another and which define a parallel resonant frequency circuit 6070a. The resistor 6072 has a resistance of about 2,500 Ohms, the capacitor 6074 has a capacitance of about .047 microfarads and the inductor 6076 has an inductance of about 33 millihenrys. The second complex impedance circuit 6080 comprises a single capacitor 6080a having a capacitance of about .0022 microfarads. The capacitor 6080a is provided in parallel with the second coil 6060b, and defines the location along a frequency axis of a peak high frequency f_{PH} of a frequency response curve C_{10}, see Fig. 37. Further provided is a resistor 6090, which is in parallel with the capacitor 6080. It has a resistance value of about 20,000 Ohms.

The capacitance, inductance and resistance values of the first and second circuits 6070 and 6080 as well as the resistor 6090 may be varied so as to alter the frequency response of the circuit 6050. More specifically, if the value of the capacitor 6074 and/or the value of the inductor 6076 is varied, the location along the frequency axis of an intermediate or reference frequency f_R of the response

curve C_{10} can be changed. If the value of the resistor 6072 is varied, the amplitude of a point on the response curve C_{10} at the reference frequency f_R and the width W_{10} of a notch portion N_{10} of the frequency response curve can be changed. If the value of the capacitor 6080a is altered, the location along the frequency axis of a peak high frequency f_{PH} of the response curve C_{10} can be changed. The frequency position of the reference frequency f_R and width of the notch portion N_{10} sets the position of the location along the frequency axis of a peak low frequency f_{PL} of the response curve C_{10} as a by product. If the value of the resistor 6090 is lowered, the amplitudes of the points at the peak low and peak high frequencies will decrease and if the value of the resistor 6090 is increased, the amplitudes of the points at the peak low and peak high frequencies will increase. By increasing the resistance of the first coil 6060a, the amplitudes of points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be lowered. By decreasing the resistance of the first coil 6060a, the amplitudes of points on the frequency response curve at the peak low frequency f_{PL} and the peak high frequency f_{PH} can be increased. By decreasing the resistance of the second coil 6060b, the amplitude of the point on the frequency response curve at the peak high frequency can be increased. The amplitude of the point on the frequency response curve at the peak high frequency can be decreased by increasing the resistance of the second coil 6060b, and/or adding a resistor (not shown) in series with the second coil 6060b.

The input of the passive circuit 6050 may be coupled directly to an audio signal source S, such as a CD player, a DAT player, a laser disc player, a tape player and the like, and the output of the passive circuit 6050 may be coupled directly to an audio amplifier, such as a pre-amplifier stage or a power amplifier stage, see Fig. 36.

Any commercially available connector(s) may be used to connect the passive circuit 6050 to the signal source and/or the audio amplifier including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the source S and the audio amplifier A. It has been found that when the passive circuit 6050 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the circuit 6050, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 37, an exemplary frequency response curve C_{10} generated by a passive circuit 6050 constructed in accordance with the tenth embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_{10} was obtained by connecting the input of the circuit 6050 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 6050 to a resistive load of 100 KOHMS, which load represented an equivalent impedance that the circuit 6050 might see when connected to a conventional audio amplifier. No active element was interposed between the input source S and the resistive load.

From curve C_{10}, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 6050. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 4.0 KHz for the 100 KOHMS load) to a peak high frequency (about 16.0 KHz for the 100 KOHMS load) and decrease in frequency from the intermediate frequency down to a range of peak low frequencies (about 100 Hz to about 2.0 KHz for a 100 KOHMS load). The amplification of the frequency component at the peak high frequency is from about 1.25 to about 6.0 and preferably about 4.0. The amplification of the frequency components within

the peak low frequency range is from about 1.1 to about 3.0 and preferably about 2.2. Hence, for curve C_{10}, the amplification of the frequency component at the peak high frequency is about 4.0 times the amplification of the intermediate frequency component at 4.0 KHz and the amplification of the frequency components within the peak low frequency range is about 2.2 times the amplification of the intermediate frequency component at 4.0 KHz.

It is also contemplated that passive circuit 6050 may be substituted for one or both of the passive circuits 800a and 800b in the two channel cable/passive circuit assembly 2000b or the single passive circuit in the one channel cable/passive circuit assembly.

It is further contemplated that resistors 6072 and 6090 may comprise potentiometers such that an operator or user of the passive circuit 6050 may adjust the frequency response of the passive circuit 6050 after it is purchased.

Exemplary Embodiment No. 11

A passive circuit 7000 comprising a transformer 7010 and first and second complex impedance circuits 7020 and 7030, constructed in accordance with an eleventh embodiment of the present invention, is illustrated in the circuit diagram of Fig. 38. The transformer 7010 includes a bobbin 7040, a ferromagnetic core 7050 and first and second magnetically coupled coils 7010a and 7010b, see Fig. 38. The first complex impedance circuit 7020 is in cascade with the first coil 7010a and the second complex impedance circuit 7030 is in parallel with the second coil 7010b.

The bobbin 7040 may be formed from a fiber reinforced polymeric material. In the illustrated embodiment, the bobbin 7040 comprises a glass fiber reinforced nylon. The bobbin 7040 has a substantially rectangular-shaped tubular portion 7042 having a core-receiving aperture 7044 extending through it, see Figs. 38A and 38B. Provided at opposite ends of the tubular portion 7042 are first and second flanges 7046 and 7048. The wall thickness of each of the tubular portion 7044 and the flanges 7046 and 7048 is about .040 inch. The width W_F and length

L_F of each flange 7046 and 7048 are about 1.48 inches and 1.54 inches, respectively. The width W_A, height H_A and length L_A of the aperture 7044 are about .765 inch, .765, and 1.02 inches, respectively. Each of the flanges 7046 and 7048 includes a pin-containing portion 7046a and 7048a having six L-shaped pins embedded therein. The six pins are designated in the drawings P_1-P_{12}. One such bobbin is commercially available from Plastron Corporation under the product designation "1152A-31-80."

The first coil 7010a of the transformer 7010 is defined by first and second primary winding portions 7012a and 7012b, which are connected in series, see Fig. 38. The second coil 7010b is defined by first and second secondary winding portions 7014a and 7014b which are connected in series.

A first wire 7013a, a type "18 single-poly-nylon(SPN) 155°C" wire, is randomly wound in a clockwise direction about the bobbin tubular portion 7044 to form the first primary winding portion 7012a. The winding portion 7012a comprises 20 turns and has a DC resistance of about .05 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_7 and P_9, see Fig. 38A. A first layer of a fiber reinforced polymeric film is wrapped about the first primary winding portion 7012a. Such a film is commercially available from TESA Inc. under the product designation "IL51596." The first film layer has a thickness of about .0045 inch.

A second wire 7015a, a type "18SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the first film layer so as to form the first secondary winding portion 7014a. The winding portion 7014a comprises 45 turns and has a DC resistance of about 0.10 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_5 and P_3. A second layer of the IL51596 fiber reinforced polymeric film is wrapped about first secondary winding portion 7014a. The second layer has a thickness of about .0045 inch.

A third wire 7013b, a type "18SPN 155ºC" wire, is randomly wound in a clockwise direction about the second film layer so as to form the second primary winding portion 7012b. The winding portion 7012b comprises 20 turns and has a DC resistance of about .05 Ohms $\pm$ 10%. The wire 7013b is soldered or otherwise

connected to pin P_9 and pin P_{11}. A third layer of the IL51596fiber reinforced polymeric film is wrapped about second primary winding portion 7012b. The third layer has a thickness of about .0045 inch. The first and second primary winding portions 7012a and 7012b of the transformer 7010 are connected in series via pin P_9 so as to define the first coil 7010a extending between pins P_7 and P_{11} having a resistance of about 0.10 Ohms.

A fourth wire 7015b, a type "18SPN 155°C" wire, is randomly wound in a counter-clockwise direction about the third film layer so as to form the second secondary winding portion 7014b. The winding portion 7014b comprises 45 turns and has a DC resistance of about 0.10 Ohms $\pm$ 10%. It is soldered or otherwise connected to pins P_3 and P_2. A fourth layer of the IL51596 fiber reinforced polymeric film is wrapped about second secondary winding portion 7014b. The fourth layer has a thickness of about .0045 inch. The first and second secondary winding portions 7014a and 7014b of the transformer 7010 are connected in series via pin P_3 so as to define the second coil 7010b extending between pins P_5 and P_2 having a resistance of about 0.20 Ohms.

The wires 7013a, 7013b, 7015a and 7015b are commercially available from the Phelps Dodge Corporation.

The core of the first transformer is formed from numerous E-core and I-core sections, in substantially the same manner as described above with regard to cores 30, 130 and 230. The E-core and I-core sections comprise a ferromagnetic material, such as a 29 gauge, M6 grade steel. In the described embodiment, each E-core section has a thickness of about .014 inch. Each I-core section has a thickness of about .014 inch. The length L_C of the core is about 2.25 inches, the thickness T_C of the core is about .75 inch, and the height H_C of the core is about 2.0 inches, when using the dimension designations illustrated in Fig. 1.

The primary winding portions 7012a and 7012b are interleaved with the secondary winding portions 7014a and 7014b so as to achieve a high degree of coupling between the primary winding portions 7012a, 7012b and the secondary winding portions 7014a, 7014b as well as to minimize the capacitance between the

winding portions 7012a, 7012b and 7014a, 7014b.

The first complex impedance circuit 7020 comprises a resistor 7022, a capacitor 7024 and an inductor 7026, all in parallel with one another. The resistor 7022 has a resistance of about 1.8 Ohms, the capacitor 7024 has a capacitance of about 27 microfarads and the inductor 7026 has an inductance of about 75 microhenrys. The first circuit 7020 is provided in cascade with the first coil 7010a and defines with the transformer 7010 a location of a peak low frequency f_{PL} of a frequency response curve C_{11}, illustrated in Fig. 39, generated for the passive circuit 7000. The second complex impedance circuit 7030 comprises a single capacitor 7030a having a capacitance of about .0027 microfarads. It is provided in parallel with the second coil 7010b, and defines with the second coil 7010b the location of a peak high frequency f_{PH} of the frequency response curve C_{11}.

The capacitance, inductance and resistance values of the first and second circuits 7020 and 7030 may be varied so as to alter the frequency response of the circuit 7000. In particular, if the value of the capacitor 7024 and/or the value of the inductor 7026 is varied, the location along the frequency axis of an intermediate or reference frequency f_R of the response curve C_{11} can be changed. If the value of the resistor 7022 is varied, the amplitude of a point on the response curve C_{11} at the reference frequency f_R can be changed. If the value of the capacitor 7030 is altered, the location along the frequency axis of a peak high frequency f_{PH} of the response curve C_{11} can be changed. The location along the frequency axis of a peak low frequency f_{PL} of the response curve C_{11} is altered as a by-product of the position of the reference frequency f_R and the width of the notch N being alternated.

The input of the passive circuit 7000 may be coupled directly to an audio amplifier A, such as a power amplifier stage, or a like amplifier device, which is capable of generating an amplified input audio signal, and the output of the passive circuit 7000 may be coupled directly to a non-powered (i.e., passive) speaker, see Fig. 39.

Any commercially available connector(s) may be used to connect the passive circuit 7000 to the amplifier A and/or the speaker including a connector for effecting a single-ended connection or a connector for effecting a balanced connection.

No active element is connected between the amplifier A and the speaker. It has been found that when the passive circuit 7000 is coupled in this manner and an input audio signal made up of frequency components within a band of frequencies having a low end and a high end is transmitted through the circuit 7000, the audio signal is distorted into an enhanced audio signal that exhibits an improved harmonic quality compared to that of the original input audio signal.

In Fig. 39, an exemplary frequency response curve C_{11} generated by a passive circuit 7000 constructed in accordance with the eleventh embodiment described above, is shown. For this curve, output voltages are plotted versus frequency for normalized input signals. The frequency response curve C_{11} was obtained by connecting the input of the circuit 7000 to a signal source S, a signal generator, which generated a 1 Volt input signal which was swept through a band of frequencies from about 20 Hz to about 22KHz and connecting the output of the circuit 7000 to a resistive load of 8.0 OHMS, which load represented an equivalent impedance that the circuit 7000 might see when connected to a conventional speaker. No active element was interposed between the input source S and the resistive load.

From curve C_{11}, it is apparent that an input audio signal made up of frequency components falling within a band of frequencies having a low end and a high end is distorted when transmitted through the passive circuit 7000. This distortion is a non-uniform amplification of the frequency components of the input audio signal. Specifically, the amplification of the frequency components in the input signal increases as the frequency components increase in frequency from an intermediate frequency (about 3.5 KHz for the 10 KOHMS load) to a peak high frequency (about 16.0 KHz for the 10 KOHMS load) and decrease in frequency from the intermediate frequency down to a peak low frequency (about 200 Hz for

a 10 KOHMS load). The amplification of the frequency components at or in the vicinity of the peak high frequency is from about 1.5 to about 6.0 and preferably about 2.0. The amplification of the frequency components at or in the vicinity the peak low frequency is from about 1.1 to about 3.0 and preferably about 1.7 . Hence, for curve C_{11}, the amplification of the frequency component at the peak high frequency is about 2.0 times the amplification of the intermediate frequency component at 3.5 KHz and the amplification of the frequency component at the peak low frequency is about 1.7 times the amplification of the intermediate frequency component at 3.5 KHz.

An enhanced audio signal, according to the present invention, exhibits an improved harmonic quality compared to that of the original input audio signal. Additional advantages and modifications will readily appear to those skilled in the art.

Furthermore, when electronic audio signals from a compact disc of music and vocals were transmitted through the circuits of the present invention and the resulting enhanced electronic audio signals re-recorded onto a cassette tape using a consumer cassette player/recorder, the sound quality of the music and vocals produced from the recorded cassette tape was perceptibly better than the same music and vocals produced directly from the compact disc. This occurred even though the compact disc format is widely recognized as producing superior sound quality compared to the cassette tape format.

It is believed that the present invention can be used to enhance electronic audio signals from sound converting equipment, for example a hearing aid, a microphone or the like, before being either recorded onto a recording medium (for example, magnetic tape or optical disk) or converted directly into acoustic sound or other sound impulses. It is also believed that an audio signal enhanced according to the present invention can be transmitted through the air or some other medium, for example, for television, radio, sonar, computer or cellular telephone use; can be transmitted through transmission lines, for example, for telephone, cable TV or computer use; can be converted directly into audible

1. A passive circuit for enhancing the quality of an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a low end and a high end, said passive circuit distorting the input signal, when transmitted therethrough, into an enhanced audio signal by distorting audible frequency components of the input audio signal such that the audible frequency components increase in amplitude as they decrease in frequency from an intermediate frequency down to a low frequency, wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal, said passive circuit comprising:

transformer structure; and

a complex impedance circuit coupled with said transformer structure for defining with said transformer structure the location of the low frequency.

2. A passive circuit as set out in claim 1, wherein said passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by amplifying the audible frequency components of the input audio signal such that the amplification increases as the audible frequency components decrease in frequency from the intermediate frequency down to the low frequency.

3. A passive circuit as set out in claim 1, wherein said transformer structure comprises first coil structure and second coil structure.

4. A passive circuit as set out in claim 3, wherein said complex impedance circuit comprises a capacitor in series with said first coil structure.

5. A passive circuit as set forth in claim 3, wherein said complex impedance circuit comprises a twin-T network in cascade with said first coil structure.

sound, for example, for use at a concert, a play, in a restaurant, or a bar; and that it can be used in any other application which includes an audio signal such as, for example, in distinguishing sonar images, etc.

It is further contemplated that the passive circuit may comprise a single transformer for non-linearly amplifying frequency components of an input audio signal such that the amplification of the frequency components in the input audio signal is increased as the frequency components decrease in frequency from an intermediate frequency e.g., about 3.5 KHz down to a peak low frequency. It is believed that amplification of the frequency component at the peak low frequency may be about 1.25 times to about 2.0 times the amplification of an intermediate frequency component or the average amplification of a range of intermediate frequency components falling within the band of frequencies of 3.5 KHz to 20 KHz.

The present invention in its broader aspects is therefore not limited to the specific details, representative apparatus and method, and illustrative examples shown and described herein. Departures may be made from such details without departing from the spirit or scope of the general inventive concept of the present invention. Therefore, the scope of the invention should be limited only by the following claims and equivalents thereof.

What is claimed is:

6. A passive circuit as set forth in claim 3, wherein said complex impedance circuit comprises a bridge-T network in cascade with said first coil structure.

7. A passive circuit as set forth in claim 3, wherein said complex impedance circuit comprises a capacitor, an inductor and a resistor in parallel with one another and together being in series with said first coil structure.

8. A passive circuit as set forth in claim 3, wherein said complex impedance circuit comprises a capacitor, an inductor and a resistor in parallel with one another and together being in cascade with said second coil structure.

9. A passive circuit as set forth in claim 1, wherein complex impedance circuit and said transformer structure function together to primarily effect the distortion of the input signal as defined by a portion of a frequency response curve, the frequency response curve portion sloping upward in amplitude from the intermediate frequency to the low frequency.

10. A passive circuit as set forth in claim 1, wherein the low frequency is a peak low frequency in the range of from about 20 Hz to about 1.0 KHz.

11. A passive circuit as set forth in claim 1, wherein the frequency component at the low frequency has an amplitude that is from about 1.5 times to about 3.0 times the amplitude of the intermediate frequency.

12. A passive circuit as set forth in claim 1, wherein the input audio signal is a converted form of an original sound, and said passive circuit is operatively adapted to distort the input audio signal such that audible sound reproduced from the enhanced audio signal sounds perceptively closer to the original sound heard live in an acoustically designed environment than audible sound reproduced from the

input audio signal heard in the same acoustically designed environment.

13. A passive circuit as set forth in claim 1, wherein said passive circuit is operatively adapted such that when the input audio signal is of music provided from a compact optical disc and the resulting enhanced audio signal is recorded onto a cassette magnetic tape, said passive circuit imparts an enhancement to the input audio signal such that audible music reproduced from the enhanced audio signal on the cassette tape is clearer and exhibits an improved sound source separation compared to audible music reproduced from the input audio signal on the compact optical disc.

14. A passive circuit as set forth in claim 1, wherein the low frequency comprises a peak low frequency, and there is a total of only two significant amplitude peaks between the low end and the high end.

15. A passive circuit as set forth in claim 1, wherein the low frequency comprises a peak low frequency, and there is a total of only two significant amplitude peaks in the range of normal human hearing.

16. A passive circuit as set forth in claim 1, wherein said transformer structure and said complex impedance circuit are positioned between an audio signal source and an amplifier.

17. A passive circuit as set forth in claim 16, wherein said audio signal source comprises a CD player, a DAT player, a laser disc player, and a tape player.

18. A passive circuit as set forth in claim 1, wherein said transformer structure

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and said complex impedance circuit are adapted to be positioned between an amplifier and a speaker.

19. A passive circuit for enhancing the quality of an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a low end and a high end, said passive circuit distorting the input signal, when transmitted therethrough, into an enhanced audio signal by distorting audible frequency components of the input audio signal such that the audible frequency components increase in amplitude as they increase in frequency from an intermediate frequency up to a high frequency, wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal, said passive circuit comprising:

transformer structure; and

a complex impedance circuit coupled with said transformer structure for defining with said transformer structure the location of the high frequency.

20. A passive circuit as set out in claim 19, wherein said passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by amplifying the audible frequency components of the input audio signal such that the amplification increases as the audible frequency components increase in frequency from the intermediate frequency up to the high frequency.

21. A passive circuit as set out in claim 19, wherein said transformer structure comprises first coil structure and second coil structure.

22. A passive circuit as set out in claim 21, wherein said complex impedance circuit comprises a capacitor in parallel with said second coil structure.

23. A passive circuit as set forth in claim 21, wherein said transformer

structure comprises a transformer comprising first and second coils, said first coil defining said first coil structure and said second coil defining said second coil structure, said second coil and said complex impedance circuit function together to primarily effect the distortion of the input signal as defined by a portion of a frequency response curve, the portion sloping upward in amplitude from the intermediate frequency to the high frequency.

24. A passive circuit as set forth in claim 19, wherein the input audio signal is a converted form of an original sound, and said passive circuit is operatively adapted to distort the input audio signal such that audible sound reproduced from the enhanced audio signal sounds perceptively closer to the original sound heard live in an acoustically designed environment than audible sound reproduced from the input audio signal heard in the same acoustically designed environment.

25. A passive circuit as set forth in claim 19, wherein said passive circuit is operatively adapted such that when the input audio signal is of music provided from a compact optical disc and the resulting enhanced audio signal is recorded onto a cassette magnetic tape, said passive circuit imparts an enhancement to the input audio signal such that audible music reproduced from the enhanced audio signal on the cassette tape is clearer and exhibits an improved sound source separation compared to audible music reproduced from the input audio signal on the compact optical disc.

26. A passive circuit as set forth in claim 19, wherein the high frequency comprises a peak high frequency, and there is a total of only two amplitude peaks between the low end and the high end.

27. A passive circuit as set forth in claim 19, wherein the high frequency comprises a peak high frequency, and there is a total of only two amplitude peaks in the range of normal human hearing.

28. A passive circuit as set forth in claim 19 wherein said transformer structure and said complex impedance circuit are positioned between an audio signal source and an amplifier.

29. A passive circuit as set forth in claim 28, wherein said audio signal source comprises a CD player, a DAT player, a laser disc player, and a tape player.

30. A passive circuit as set forth in claim 19, wherein said transformer structure and said complex impedance circuit are adapted to be positioned between an amplifier and a speaker.

31. A passive circuit for enhancing the quality of an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a low end and a high end, said passive circuit distorting the input signal, when transmitted therethrough, into an enhanced audio signal by distorting audible frequency components of the input audio signal such that a first set of the audible frequency components increase in amplitude as they decrease in frequency from a first intermediate frequency down to a low frequency and a second set of audible frequency components increase in amplitude as they increase in frequency from a second intermediate frequency up to a high frequency, wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal, said passive circuit comprising:

transformer structure;

a first complex impedance circuit coupled with said transformer structure for defining with said transformer structure the location of the low frequency; and

a second complex impedance circuit coupled with said transformer structure for defining with said transformer structure the location of the high frequency.

32. A passive circuit as set out in claim 31, wherein said transformer structure comprises first coil structure and second coil structure.

33. A passive circuit as set out in claim 32, wherein said first complex impedance circuit comprises a capacitor in series with said first coil structure.

34. A passive circuit as set forth in claim 32, wherein said first complex impedance circuit comprises a twin-T network in cascade with said first coil structure.

35. A passive circuit as set forth in claim 32, wherein said first complex impedance circuit comprises a bridge-T network in cascade with said first coil structure.

36. A passive circuit as set forth in claim 32, wherein said first complex impedance circuit comprises a capacitor, an inductor and a resistor in parallel with one another and together being in series with said first coil structure.

37. A passive circuit as set forth in claim 32, wherein said first complex impedance circuit comprises a capacitor, an inductor and a resistor in parallel with one another and together being in cascade with said second coil structure.

38. A passive circuit as set out in claim 32, wherein said second complex impedance circuit comprises a capacitor in parallel with said second coil structure.

39. A passive circuit as set forth in claim 31, wherein said first complex impedance circuit and said transformer structure function together to primarily effect the distortion of the input signal as defined by a first portion of a frequency response curve, the first portion sloping upward in amplitude from the first

intermediate frequency to the low frequency, and said second complex impedance circuit and said transformer structure function together to primarily effect the distortion of the input signal as defined by a second portion of the frequency response curve, the second portion sloping upward in amplitude from the second intermediate frequency to the high frequency.

40. A passive circuit as set forth in claim 39, wherein the first portion of the frequency response curve non-linearly slopes upward in amplitude from the first intermediate frequency to the low frequency and the second portion of the frequency response curve non-linearly slopes upward in amplitude from the second intermediate frequency to the high frequency.

41. A passive circuit as set forth in claim 31, wherein the input audio signal is a converted form of an original sound, and said passive circuit is operatively adapted to distort the input audio signal such that audible sound reproduced from the enhanced audio signal sounds perceptively closer to the original sound heard live in an acoustically designed environment than audible sound reproduced from the input audio signal heard in the same acoustically designed environment.

42. A passive circuit as set forth in claim 31, wherein said passive circuit is operatively adapted such that when the input audio signal is of music provided from a compact optical disc and the resulting enhanced audio signal is recorded onto a cassette magnetic tape, said passive circuit imparts an enhancement to the input audio signal such that audible music reproduced from the enhanced audio signal on the cassette tape is clearer and exhibits an improved sound source separation compared to audible music reproduced from the input audio signal on the compact optical disc.

43. A passive circuit as set forth in claim 31, wherein the low frequency comprises a peak low frequency and the high frequency comprises a peak high

frequency, and there is a total of only two amplitude peaks between the low end and the high end.

44. A passive circuit as set forth in claim 31, wherein the low frequency comprises a peak low frequency and the high frequency comprises a peak high frequency, and there is a total of only two amplitude peaks in the range of normal human hearing.

45. A passive circuit as set forth in claim 31, wherein the first intermediate frequency and the second intermediate frequency comprise the same frequency.

46. A passive circuit as set out in claim 31, wherein said passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by amplifying the audible frequency components of the input audio signal such that the amplification increases as the audible frequency components increase in frequency from the first intermediate frequency down to the low frequency, and from the second intermediate frequency up to the high frequency.

47. A passive circuit as set out in claim 31, wherein said passive circuit distorts a substantial number of the audible frequency components of the input audio signal such that a first set of the substantial number of audible frequency components increase in amplitude as they decrease in frequency from the first intermediate frequency down to the low frequency and a second set of the substantial number of the audible frequency components increase in amplitude as they increase in frequency from the second intermediate frequency up to the high frequency.

48. A passive circuit as set out in claim 31, wherein said passive circuit distorts the input signal, when transmitted therethrough, into an enhanced audio signal by non-uniformly amplifying the audible frequency components of the input audio

signal.

49. A passive circuit as set out in claim 31, wherein said passive circuit distorts a majority of the frequency components.

50. A passive circuit as set out in claim 31, wherein the input audio signal is provided by at least one of a microphone, a recording medium player, a radio, a television, sonar, a computer, a hearing aid, and a telephone.

51. A passive circuit as set forth in claim 31, wherein said passive circuit is incorporated within a cable/passive circuit assembly.

52. A passive circuit as set forth in claim 31, wherein said passive circuit is coupled to an input audio signal source via a connector.

53. A passive circuit as set forth in claim 31, wherein said transformer structure and said first and second complex impedance circuits are positioned between an audio signal source and an amplifier.

54. A passive circuit as set forth in claim 53, wherein said audio signal source comprises a CD player, a DAT player, a laser disc player, and a tape player.

55. A passive circuit as set forth in claim 31, wherein said transformer structure and said first and second complex impedance circuits are positioned between an amplifier and a speaker.

56. A method of enhancing the quality of electronic audio signals, comprising the steps of:

providing an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a high end and a low end;

providing a passive circuit comprising transformer structure and a complex impedance circuit coupled to said transformer structure; and

passively distorting the input audio signal into an enhanced audio signal by passing said input audio signal through said passive circuit to distort frequency components of the input audio signal such that the frequency components increase in amplitude as they decrease in frequency from an intermediate frequency down to a low frequency, the location of the low frequency being defined by said complex impedance circuit together with said transformer structure, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal.

57. A method of enhancing the quality of electronic audio signals, comprising the steps of:

providing an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a high end and a low end;

providing a passive circuit comprising transformer structure and a complex impedance circuit coupled to said transformer structure; and

passively distorting the input audio signal into an enhanced audio signal by passing said input audio signal through a passive circuit to distort frequency components of the input audio signal such that the frequency components increase in amplitude as they increase in frequency from an intermediate frequency up to a high frequency, the location of the high frequency being defined by said complex impedance circuit together with said transformer structure, and wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal.

58. A method of enhancing the quality of electronic audio signals, comprising the steps of:

providing an input audio signal comprising a plurality of frequency components within a band of audible frequencies having a high end and a low end;

providing a passive circuit comprising transformer structure, a first complex impedance circuit coupled to said first coil structure and a second complex impedance circuit coupled to said second coil structure; and

passively distorting the input audio signal into an enhanced audio signal by passing said input audio signal through a passive circuit to distort frequency components such that a first set of the frequency components increase in amplitude as they decrease in frequency from a first intermediate frequency down to a low frequency and a second set of the frequency components increase in amplitude as they increase in frequency from a second intermediate frequency up to a high frequency, wherein audible sound reproduced from the enhanced audio signal exhibits a perceptively improved harmonic quality compared to audible sound reproduced from the input audio signal.

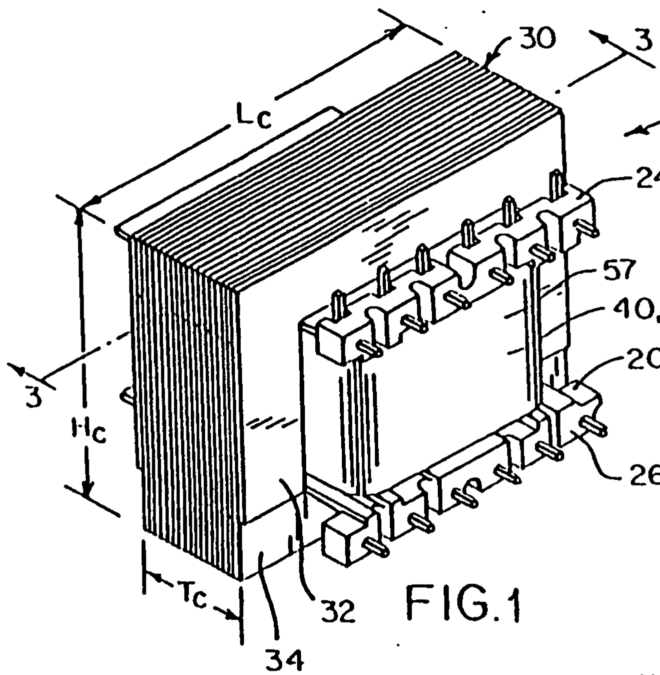


FIG.1

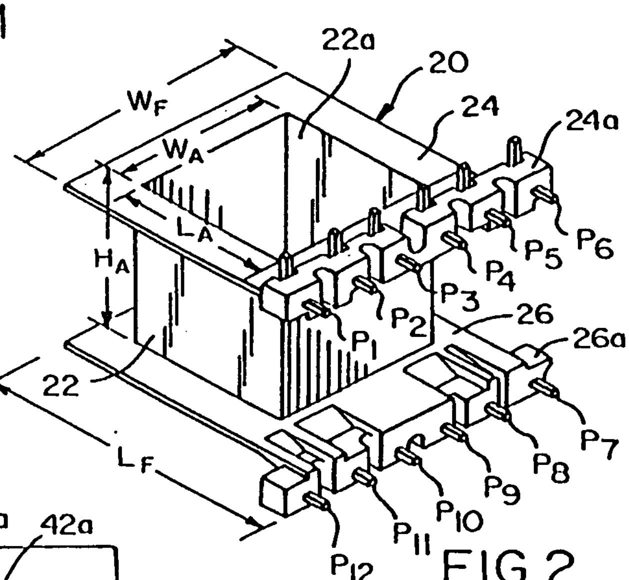


FIG.2

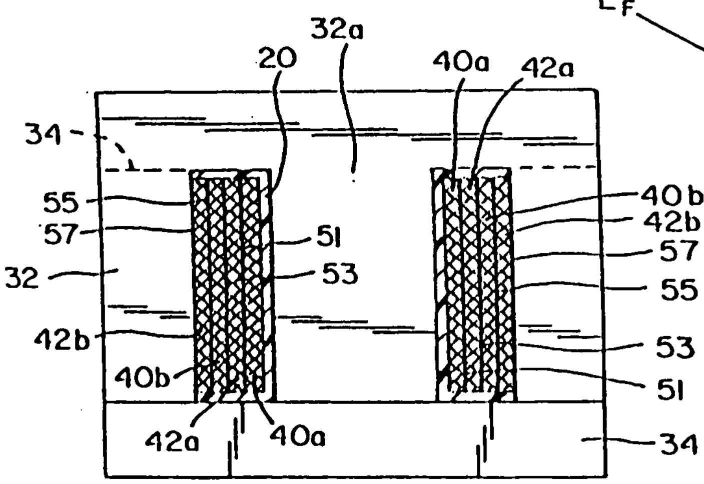


FIG.3

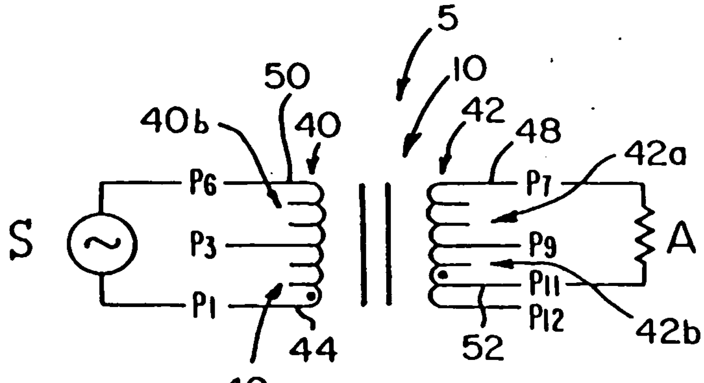


FIG.5

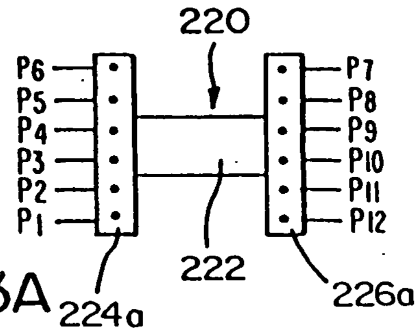


FIG.13A

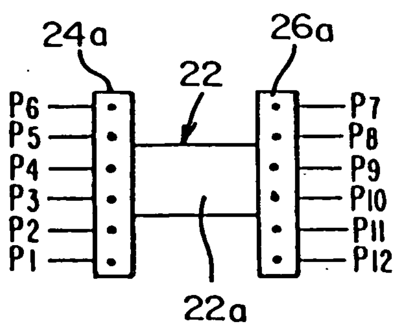


FIG.4

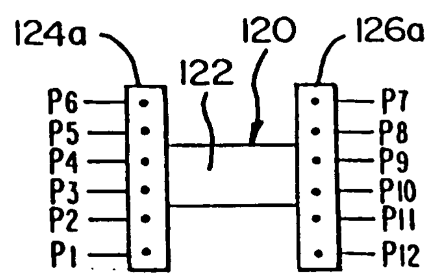


FIG.10A

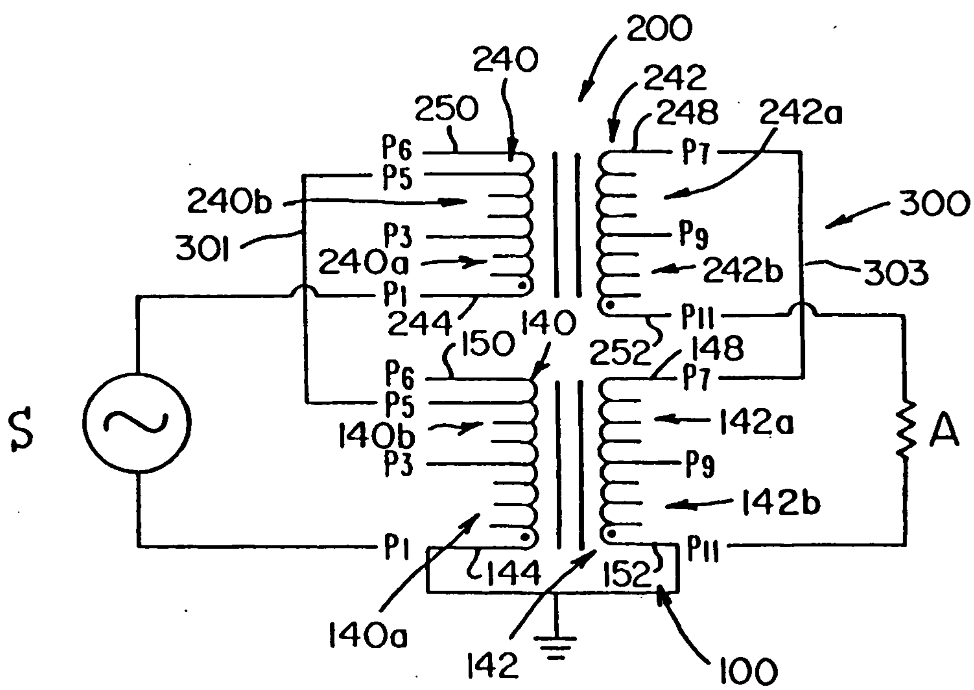


FIG.8

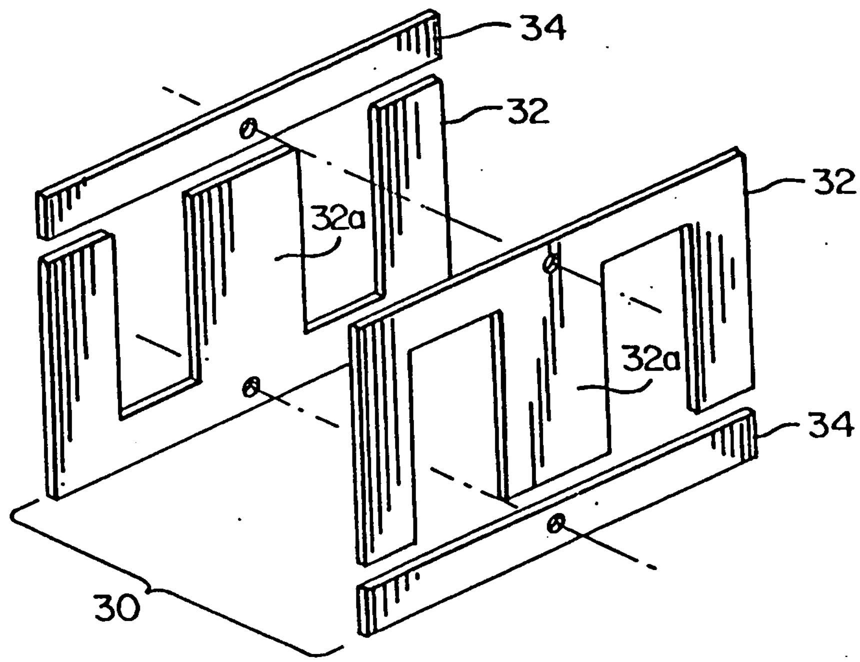


FIG.6

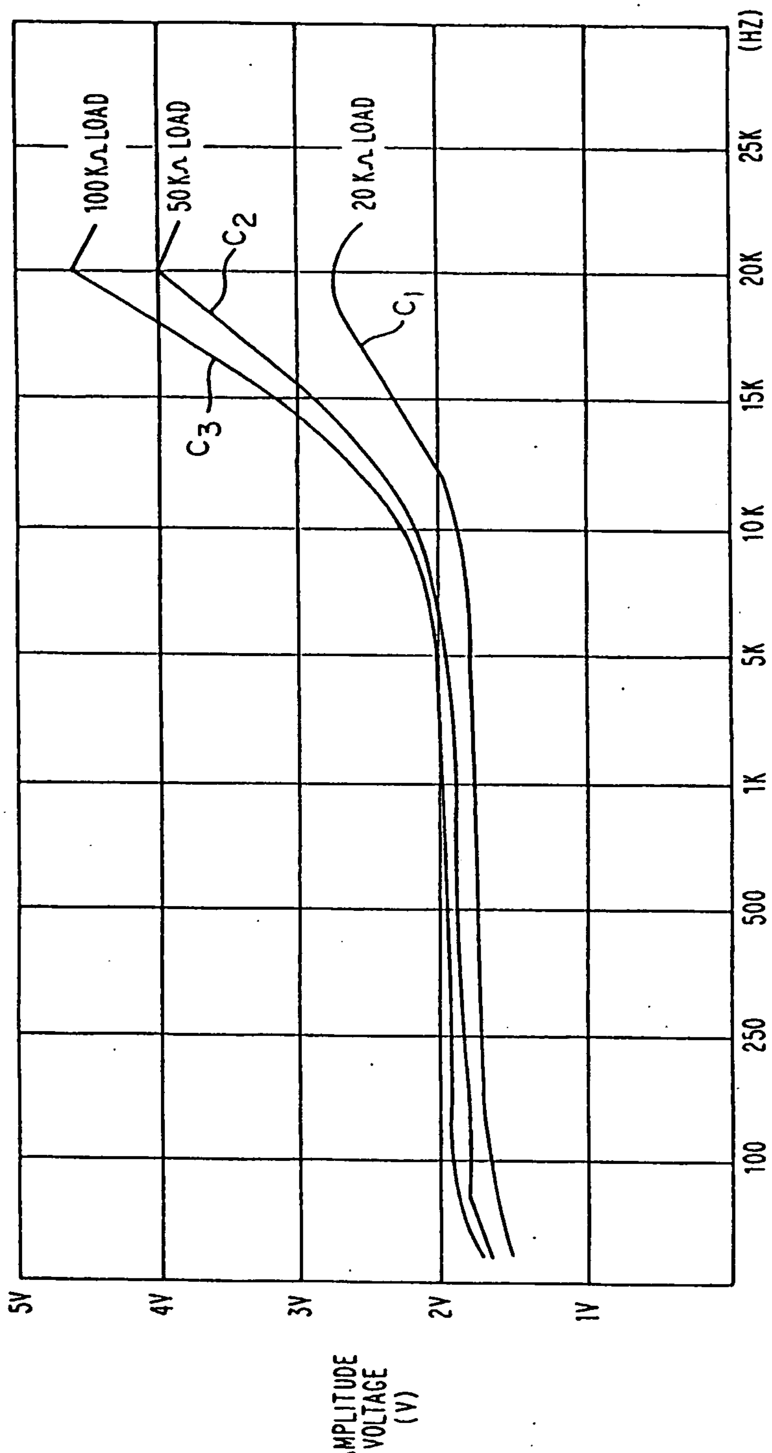

100 KΩ LOAD
50 KΩ LOAD
20 KΩ LOAD
C1
C2
C3
(HZ)
25K
20K
15K
10K
5K
1K
500
250
100
5V
4V
3V
2V
1V
AMPLITUDE
VOLTAGE
(V)

FIG. 7

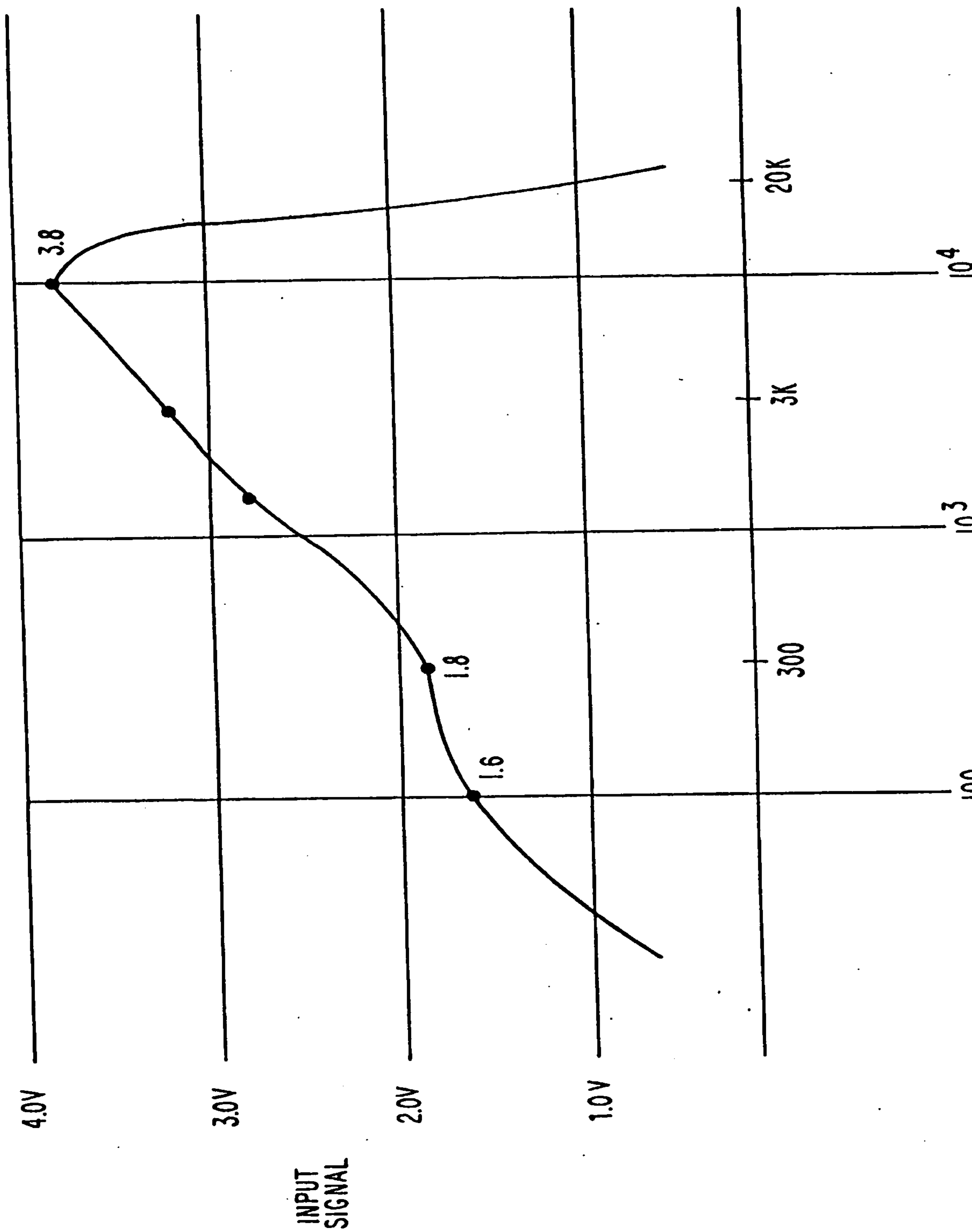


FIG. 7A

FIG. 7B

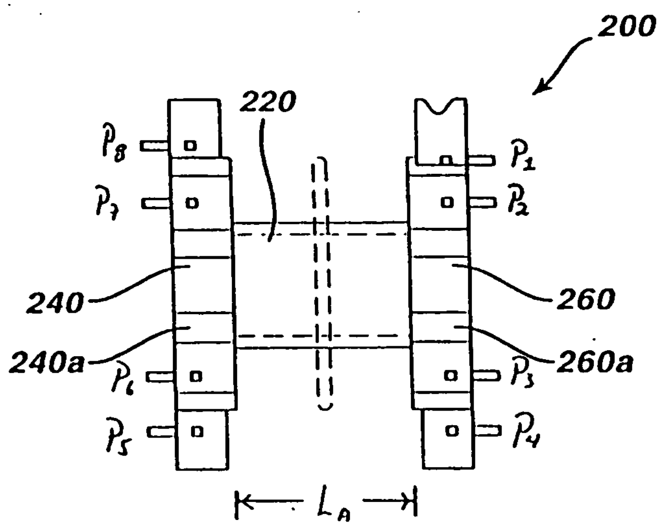

200
220
P_8
P_7
P_1
P_2
240
260
240a
260a
P_6
P_3
P_5
P_4
L_A

FIG. 7C

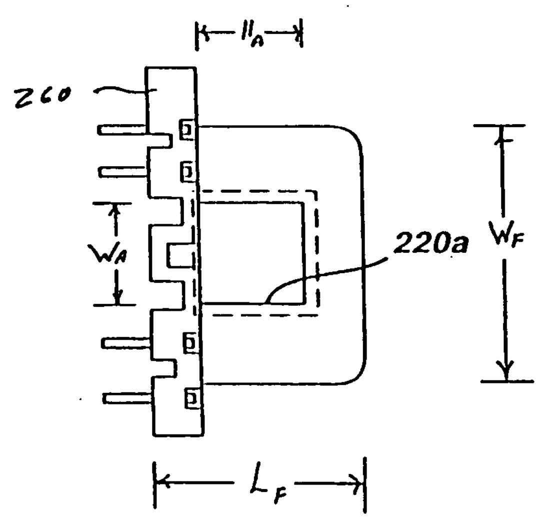
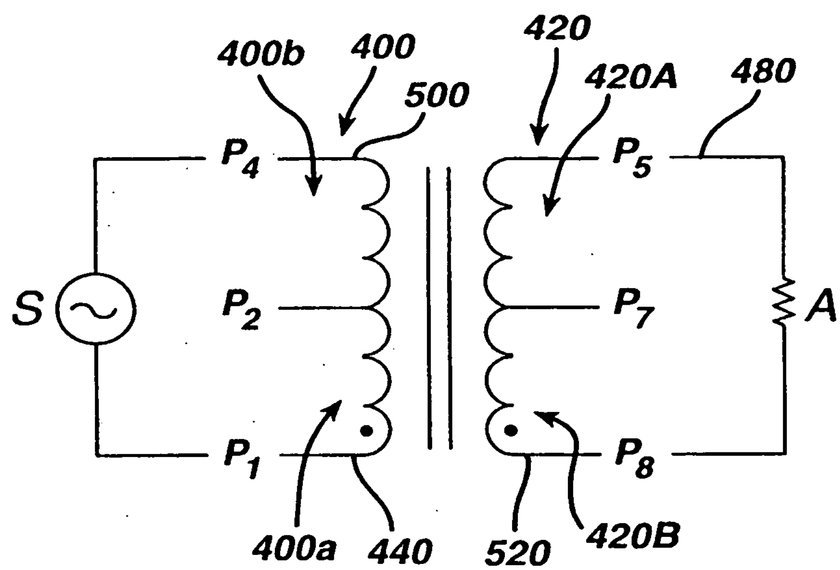

H_A
260
W_A
220a
W_F
L_F

FIG. 7D



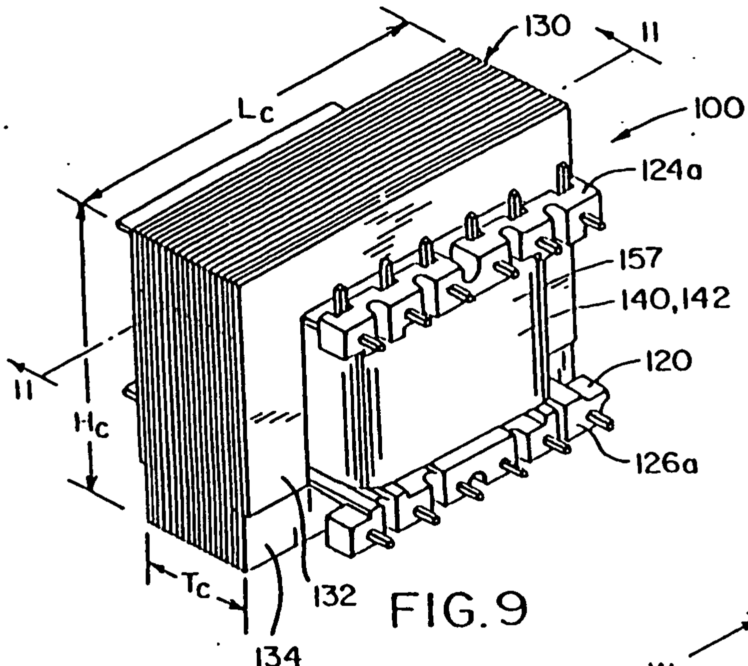


FIG.9

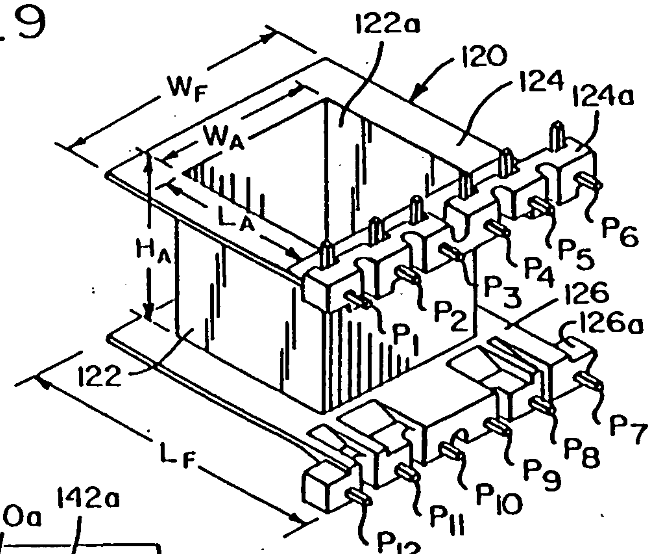


FIG.10

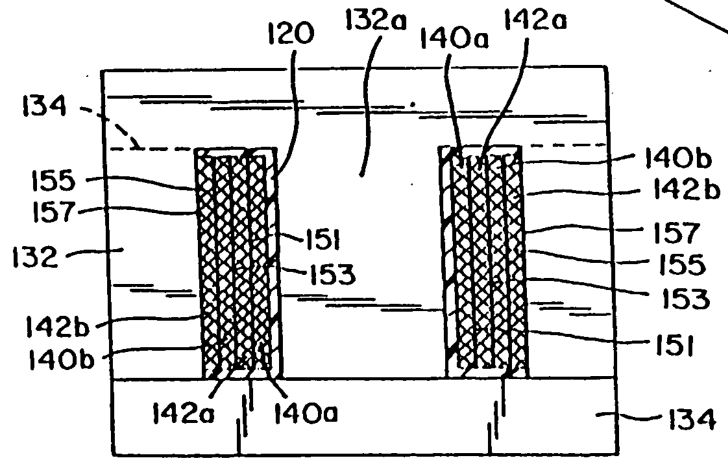


FIG.11

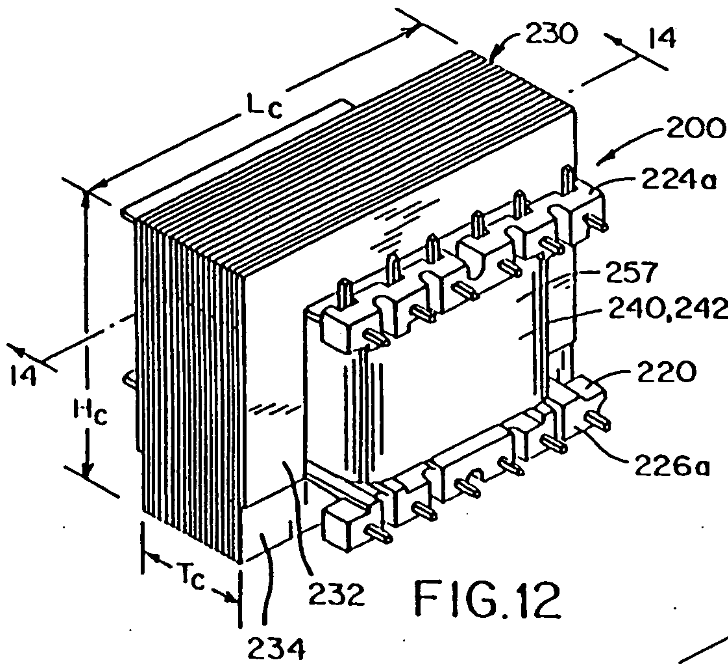


FIG.12

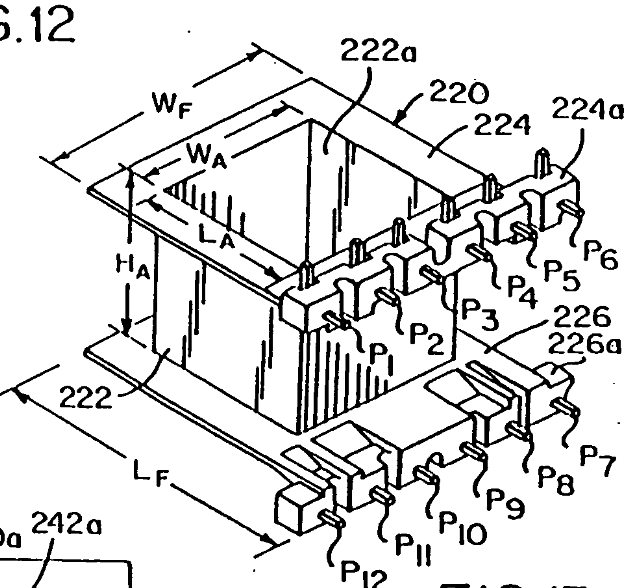


FIG.13

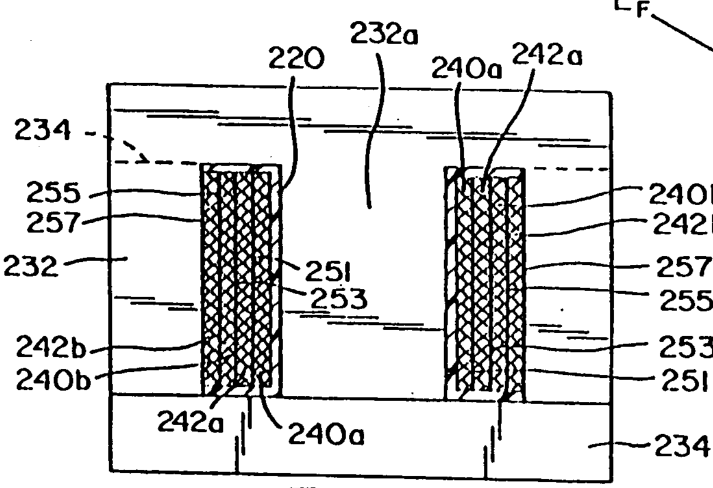


FIG.14

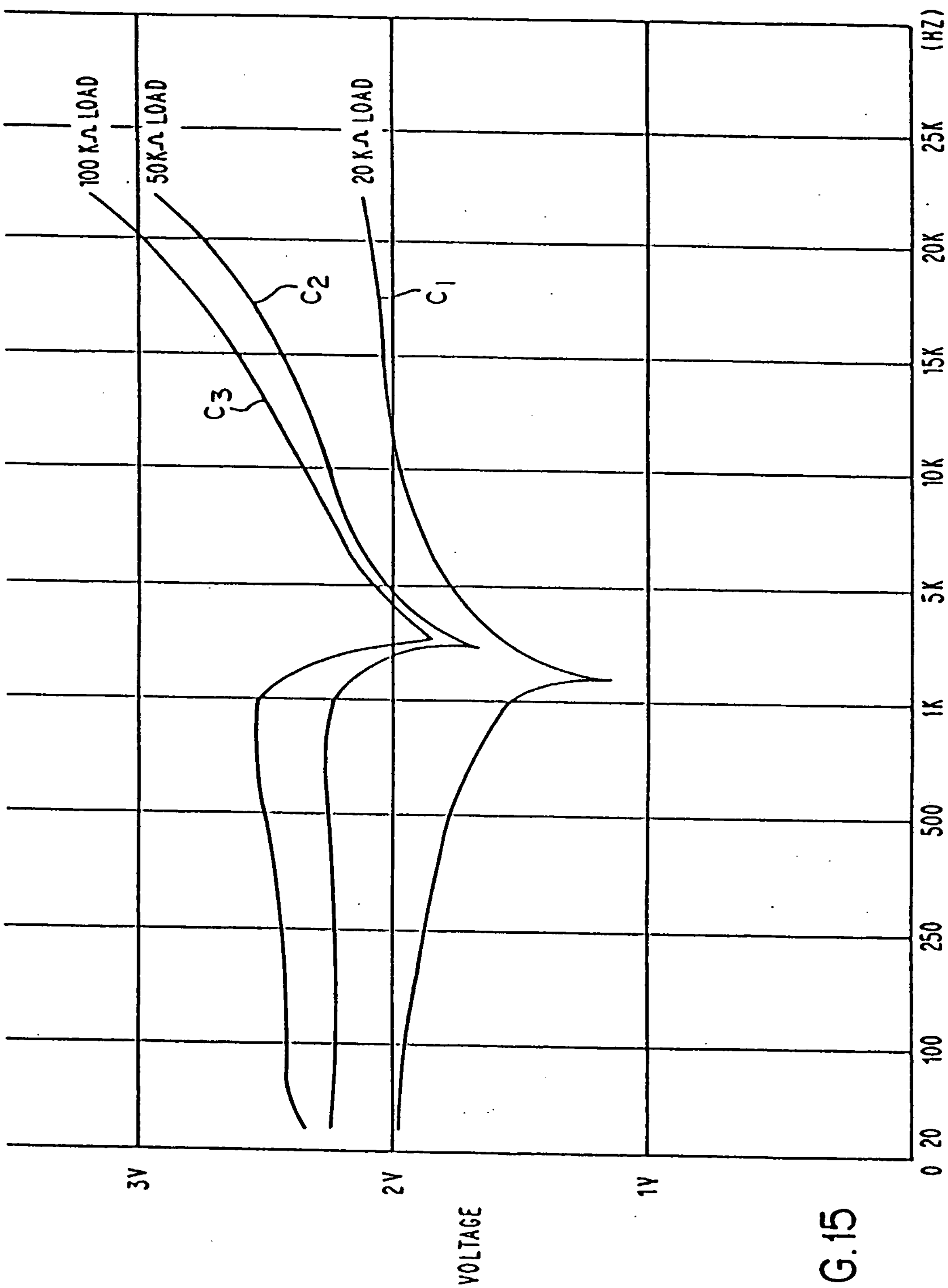

100 KΩ LOAD
50KΩ LOAD
20 KΩ LOAD
C1
C2
C3
3V
2V
1V
VOLTAGE
0
20
100
250
500
1K
5K
10K
15K
20K
25K
(HZ)

FIG.15

FIG. 16

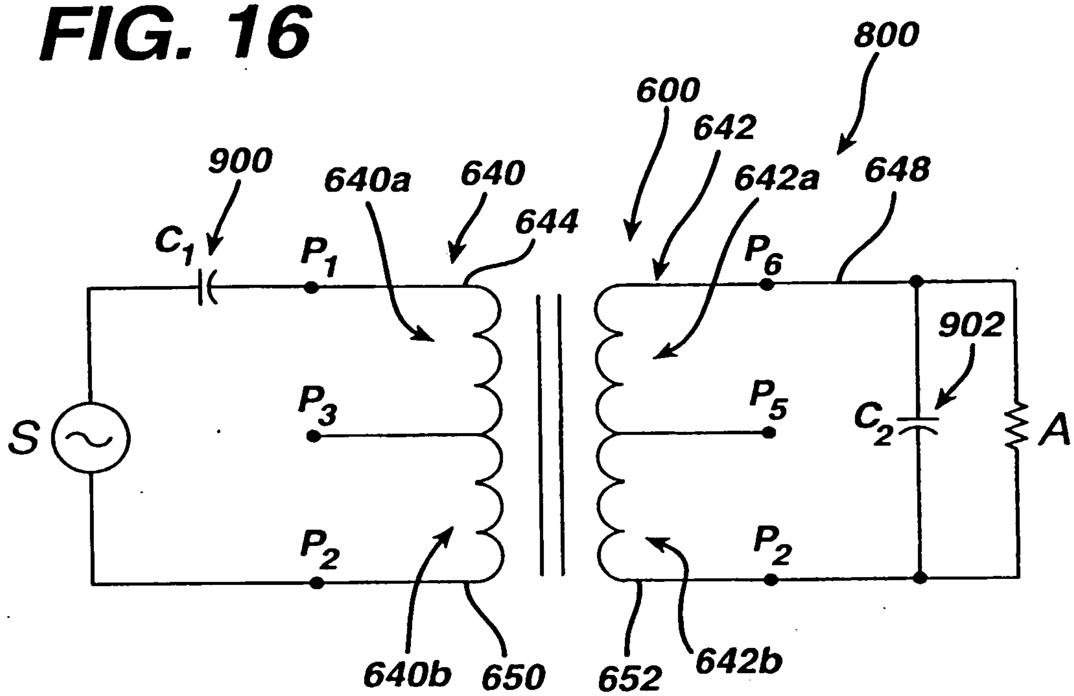

800
600
642
900
640a
640
642a
648
644
C_1
P_1
P_6
902
P_3
P_5
S
C_2
A
P_2
P_2
640b
650
652
642b

FIG. 17

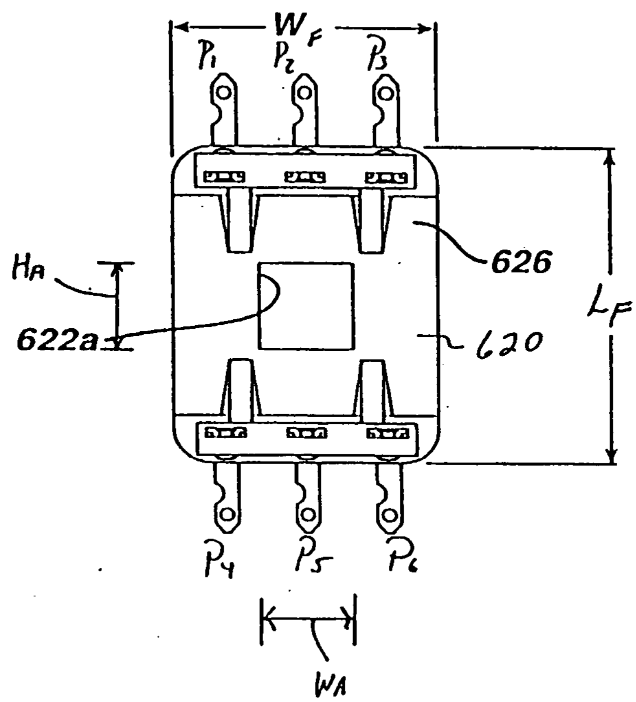


FIG. 18

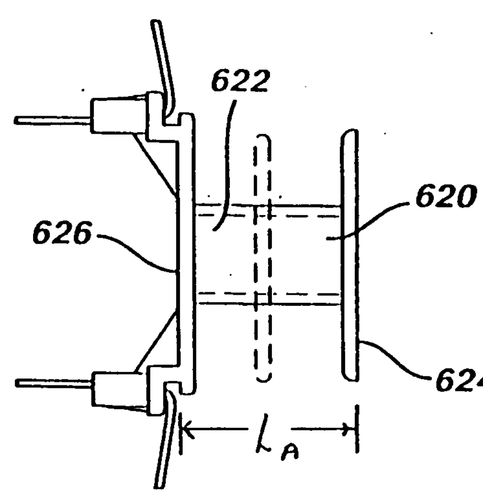


FIG. 19

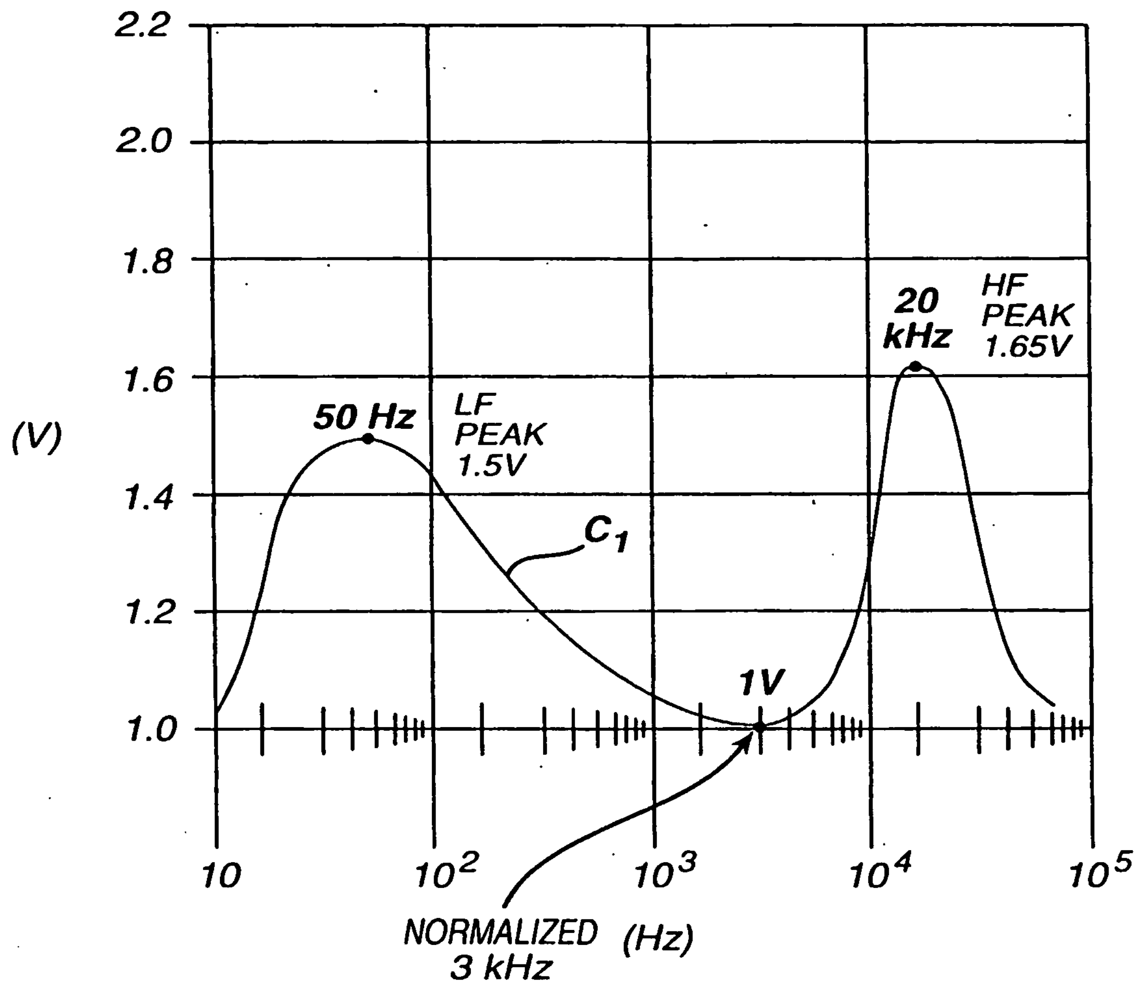
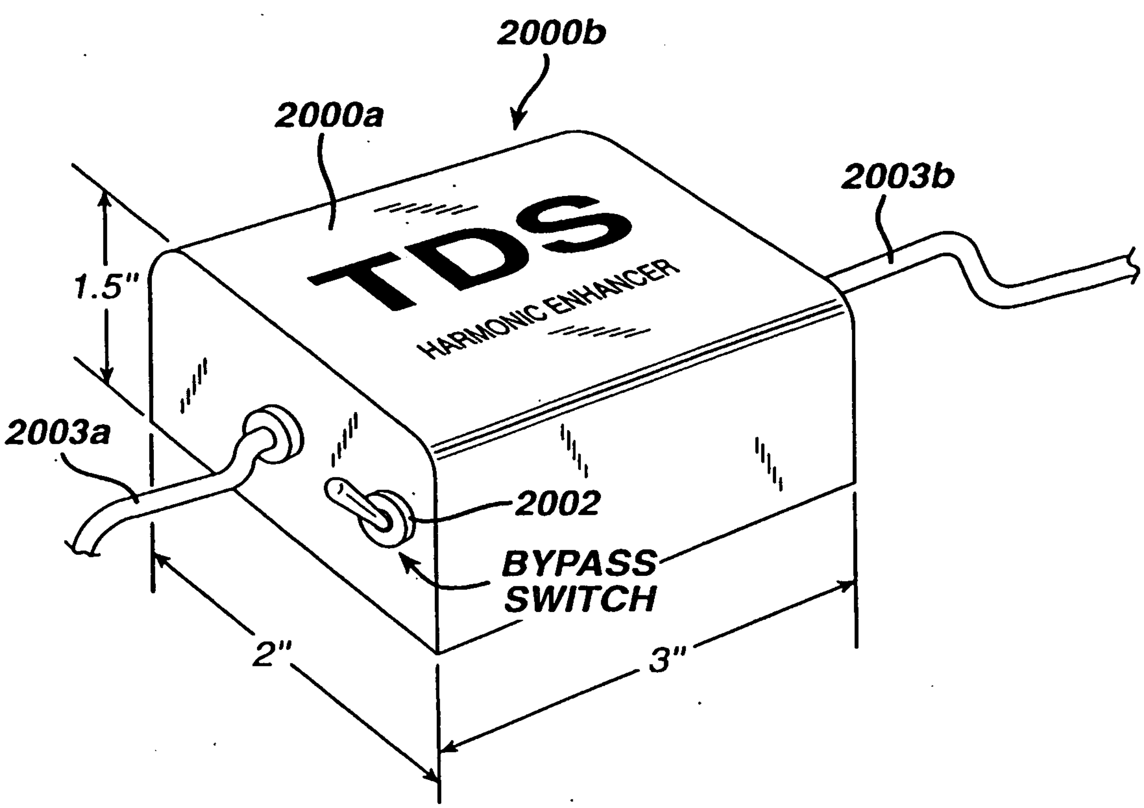

2.2
2.0
1.8
1.6
1.4
1.2
1.0
(V)
50 Hz
LF PEAK 1.5V
20 kHz
HF PEAK 1.65V
C_1
1V
10
10^2
10^3
10^4
10^5
NORMALIZED 3 kHz
(Hz)

FIG. 19A


2000b
2000a
2003b
TDS
HARMONIC ENHANCER
1.5"
2003a
2002
BYPASS SWITCH
2"
3"

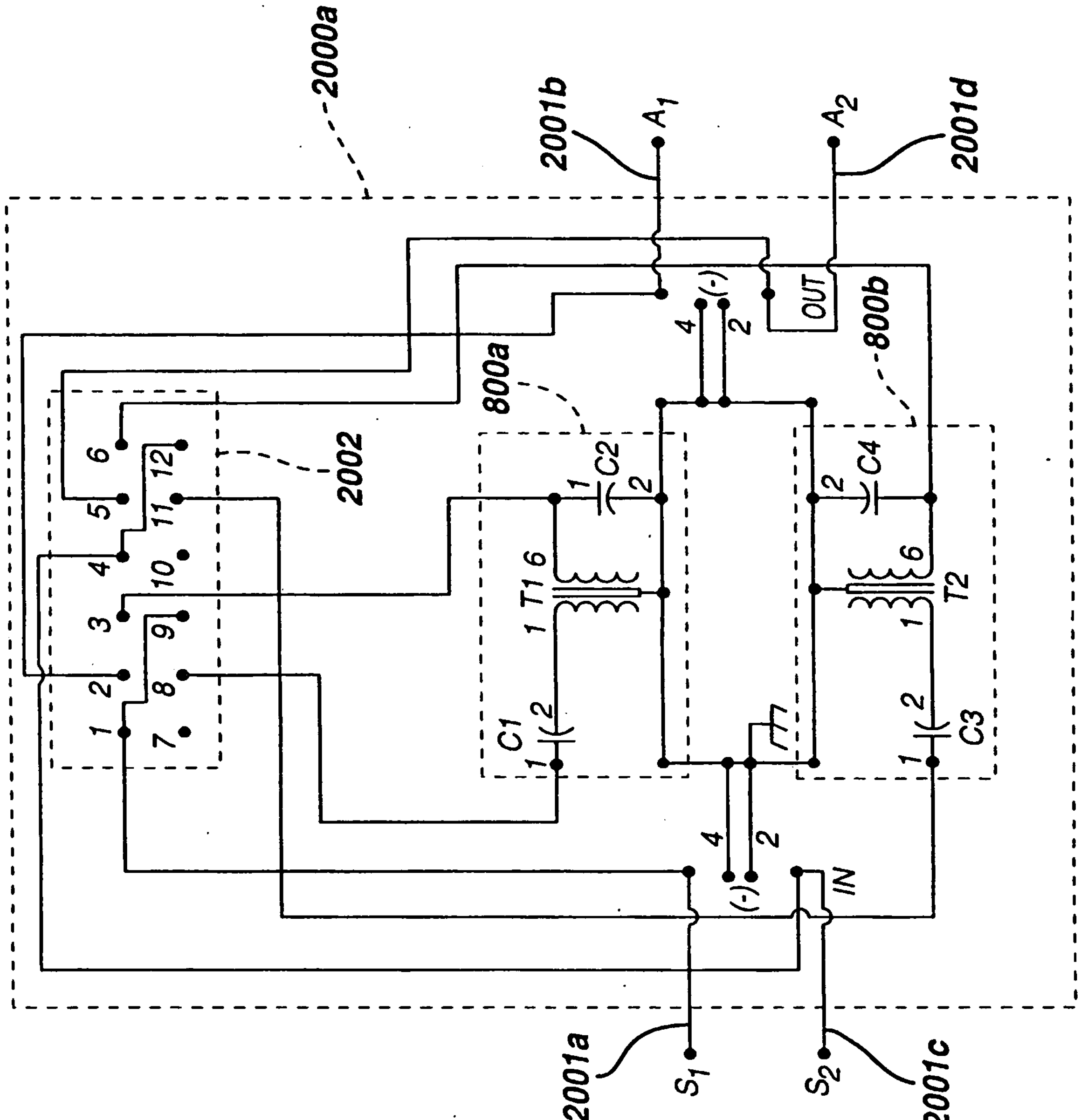

2000a
2001b
A1
A2
2001d
OUT
(-)
4
2
800a
800b
2002
6
5
4
3
2
1
12
11
10
9
8
7
C1
C2
C3
C4
T1
T2
IN
2001a
S1
S2
2001c

FIG. 19B

FIG. 20

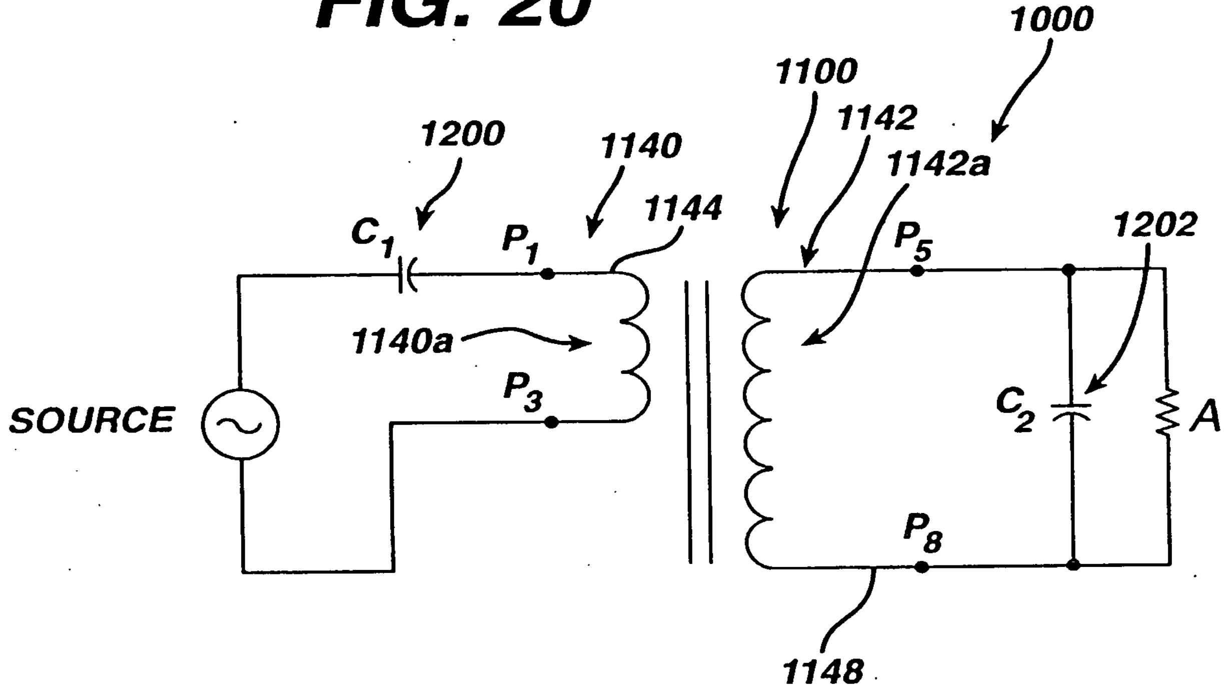

1000
1100
1142
1142a
1200
1140
1144
C_1
P_1
P_5
1202
1140a
P_3
SOURCE
C_2
A
P_8
1148

FIG. 21

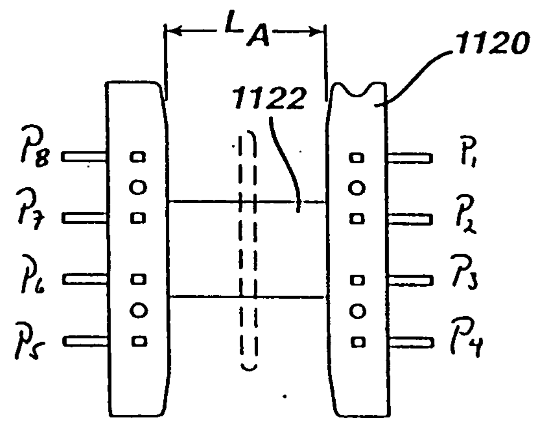
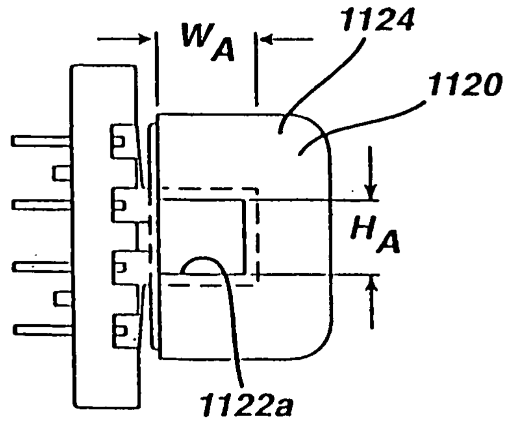


FIG. 22



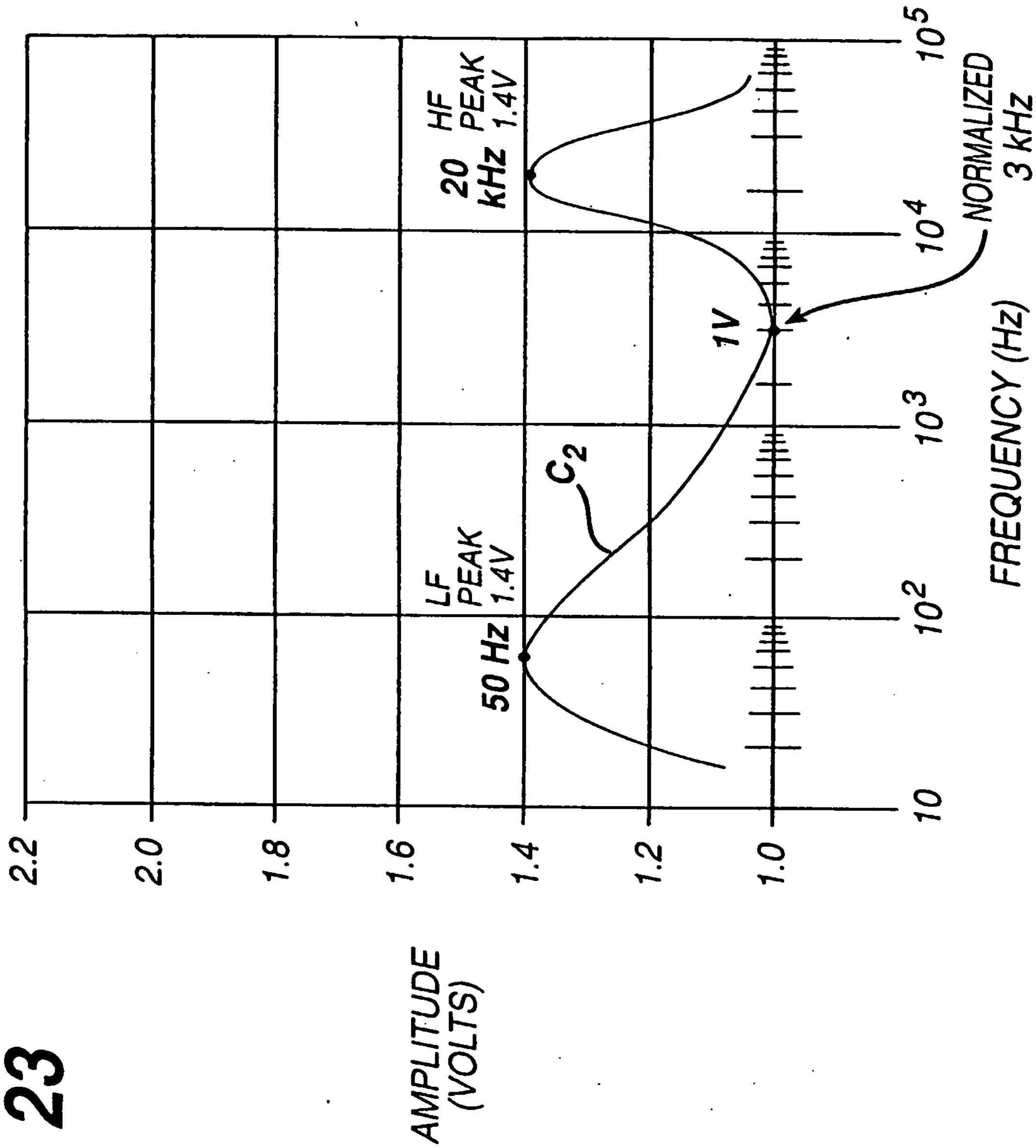

AMPLITUDE (VOLTS)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
10
10^2
10^3
10^4
10^5
FREQUENCY (Hz)
LF PEAK 1.4V
50 Hz
C_2
1V
NORMALIZED 3 kHz
20 kHz
HF PEAK 1.4V

FIG. 23

FIG. 24

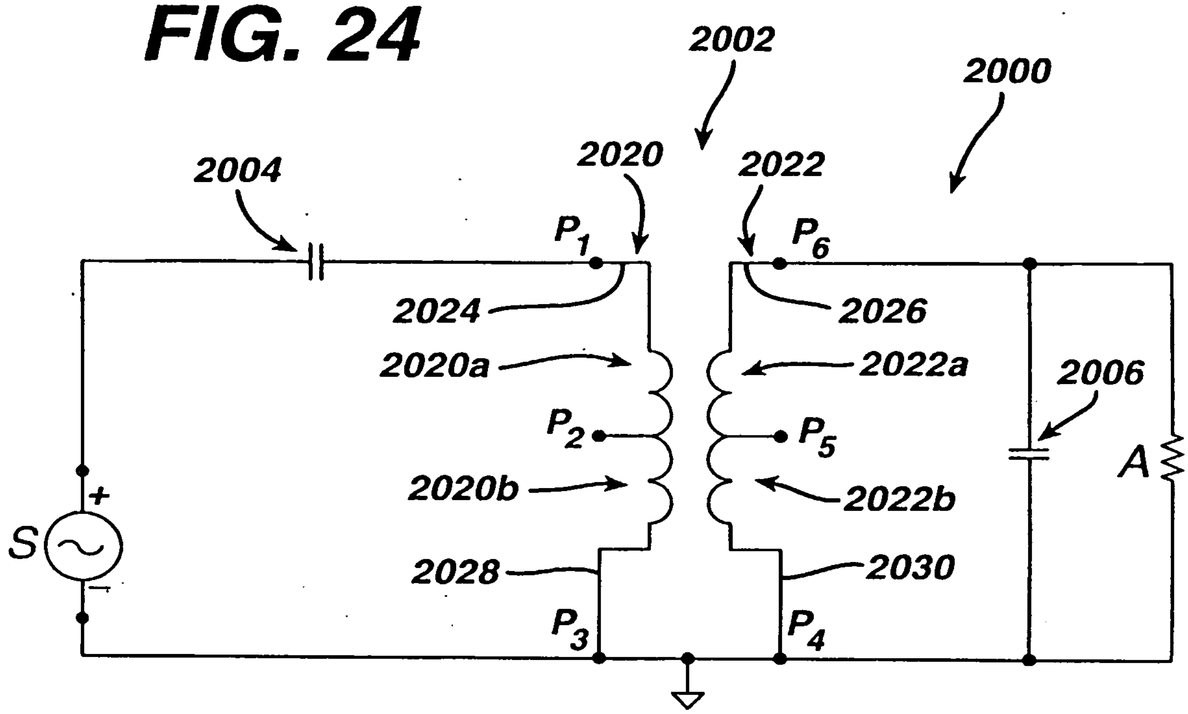
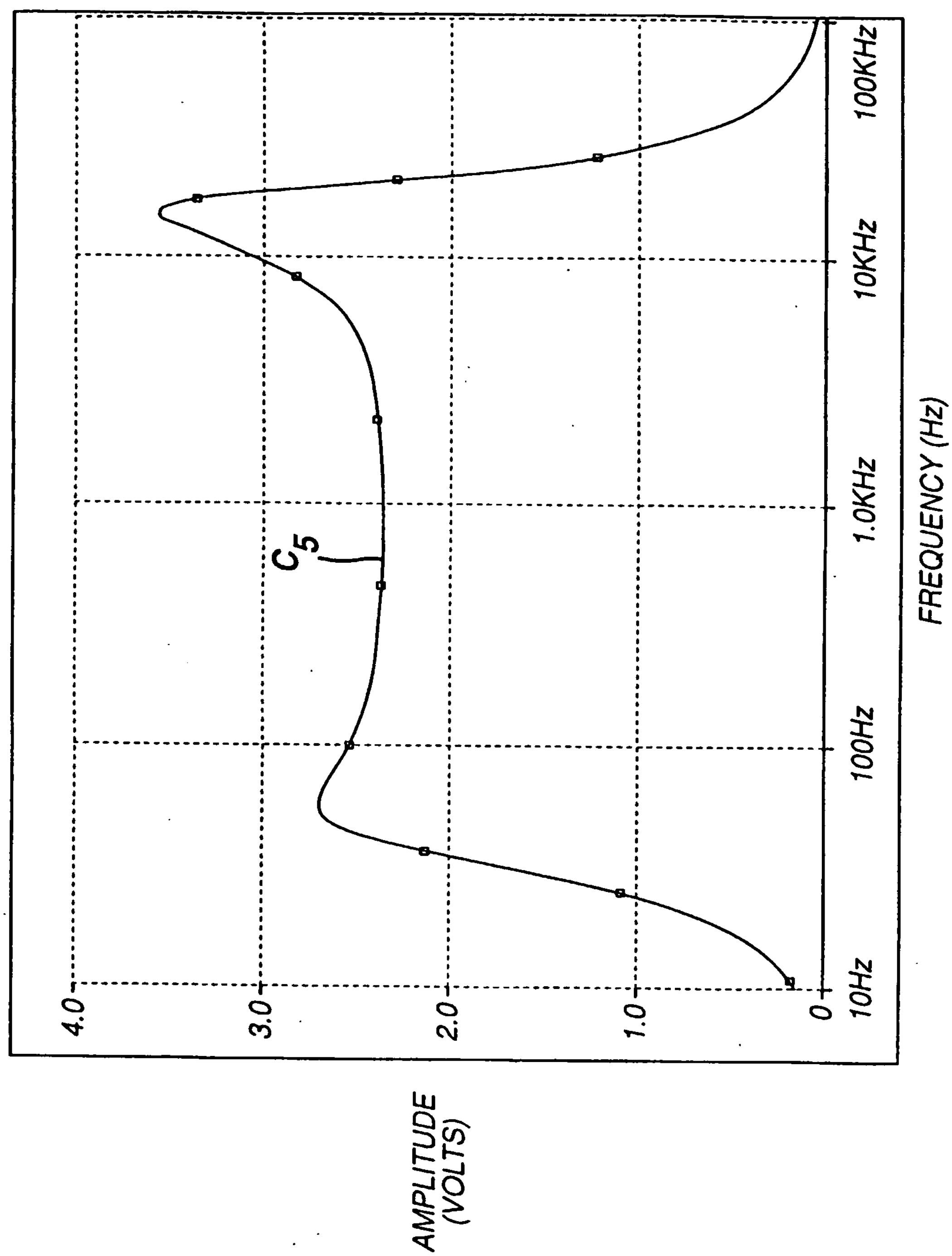

2002
2000
2020
2022
2004
P1
P6
2024
2026
2020a
2022a
2006
P2
P5
A
2020b
2022b
S
+
2028
2030
P3
P4

FIG. 25


AMPLITUDE
(VOLTS)
4.0
3.0
2.0
1.0
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
FREQUENCY (Hz)
C_5

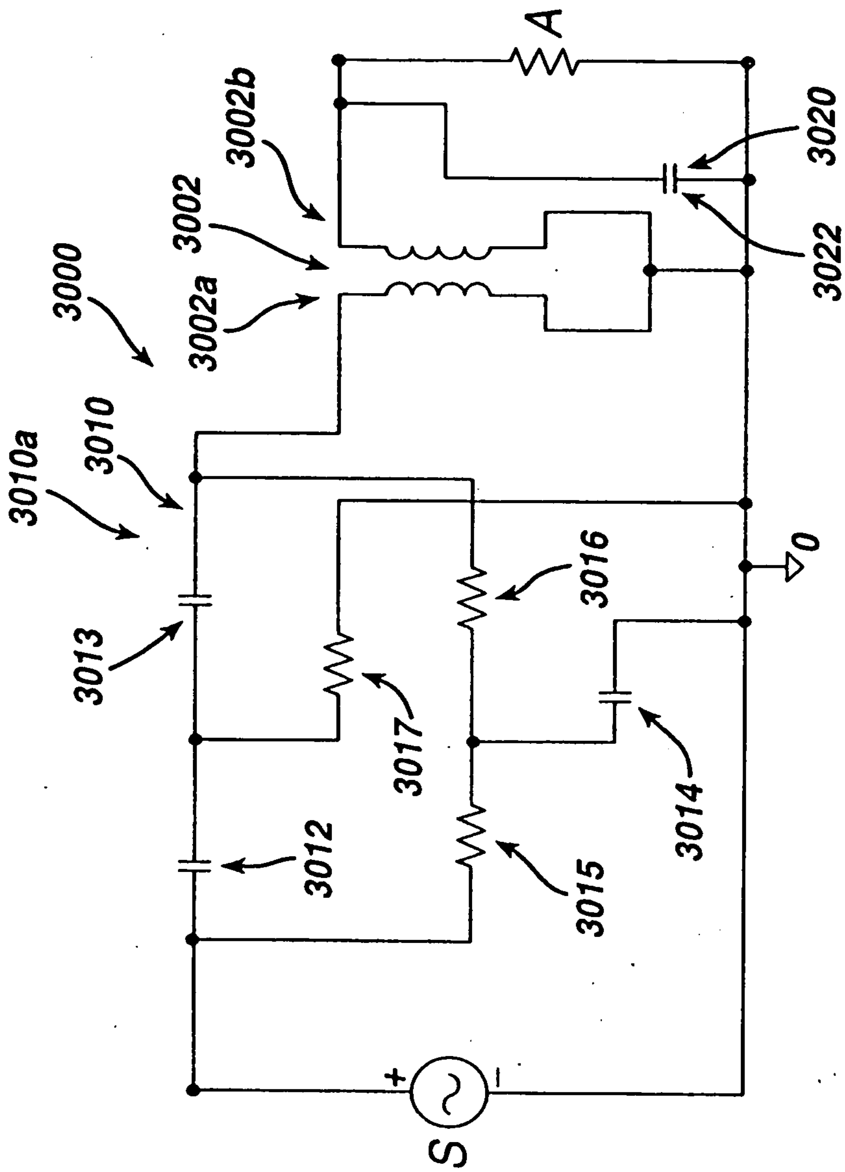

3000
3002
3002a
3002b
A
3020
3022
3010
3010a
3013
3012
3017
3016
3015
3014
0
S
+
-

FIG. 26

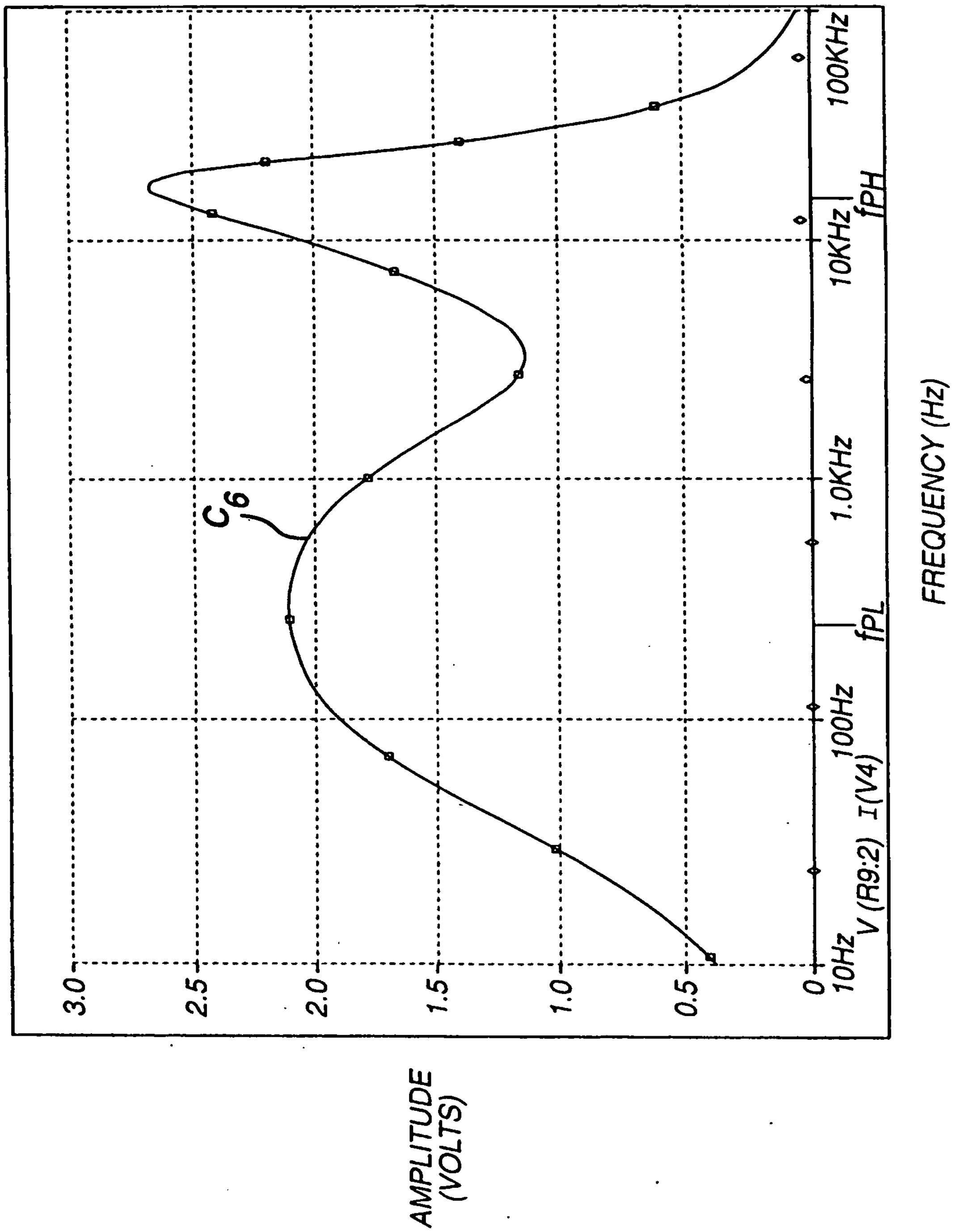

AMPLITUDE
(VOLTS)
3.0
2.5
2.0
1.5
1.0
0.5
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
fPL
fPH
C6
V (R9:2) I(V4)
FREQUENCY (Hz)

FIG. 27

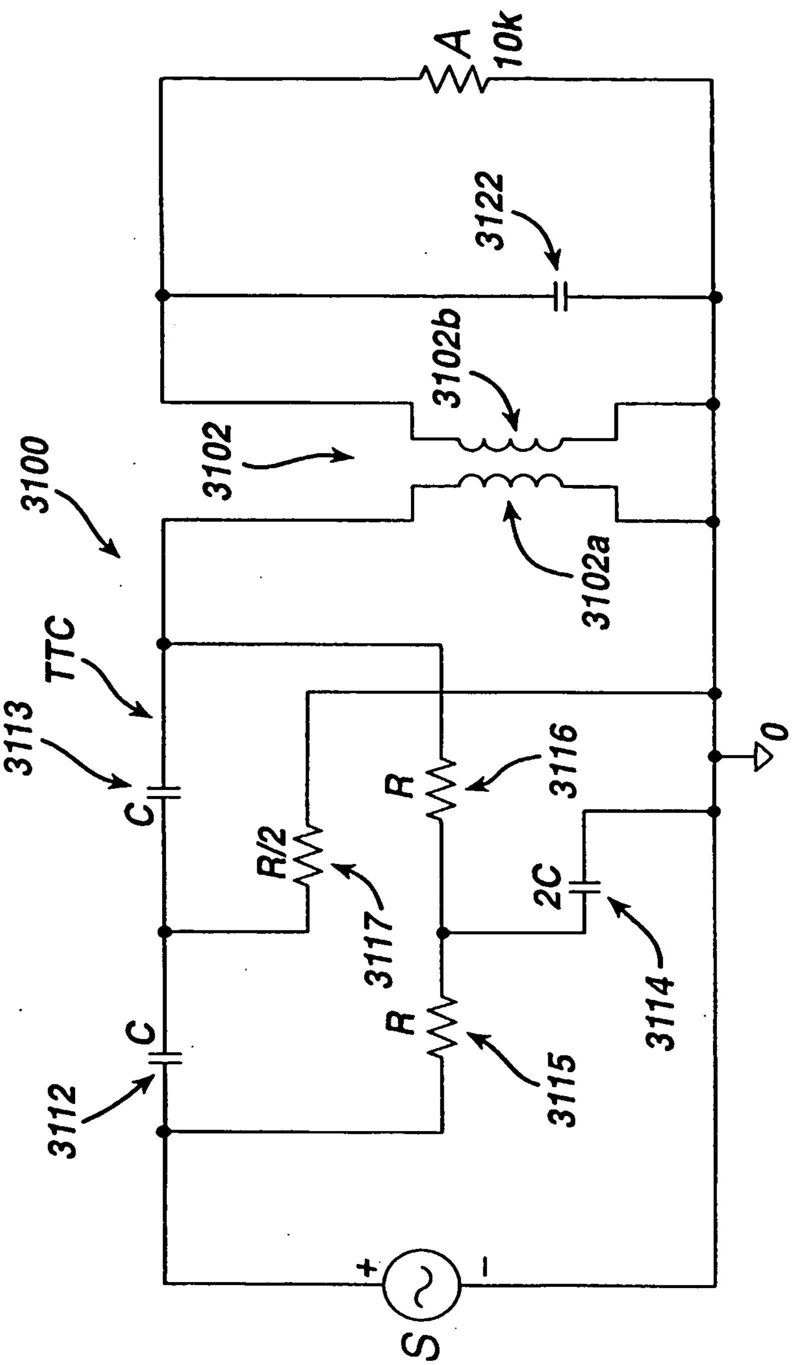

A
10k
3122
3102b
3100
3102
3102a
TTC
3113
C
R/2
R
3116
0
2C
3117
3114
C
R
3112
3115
+
-
S

FIG. 28

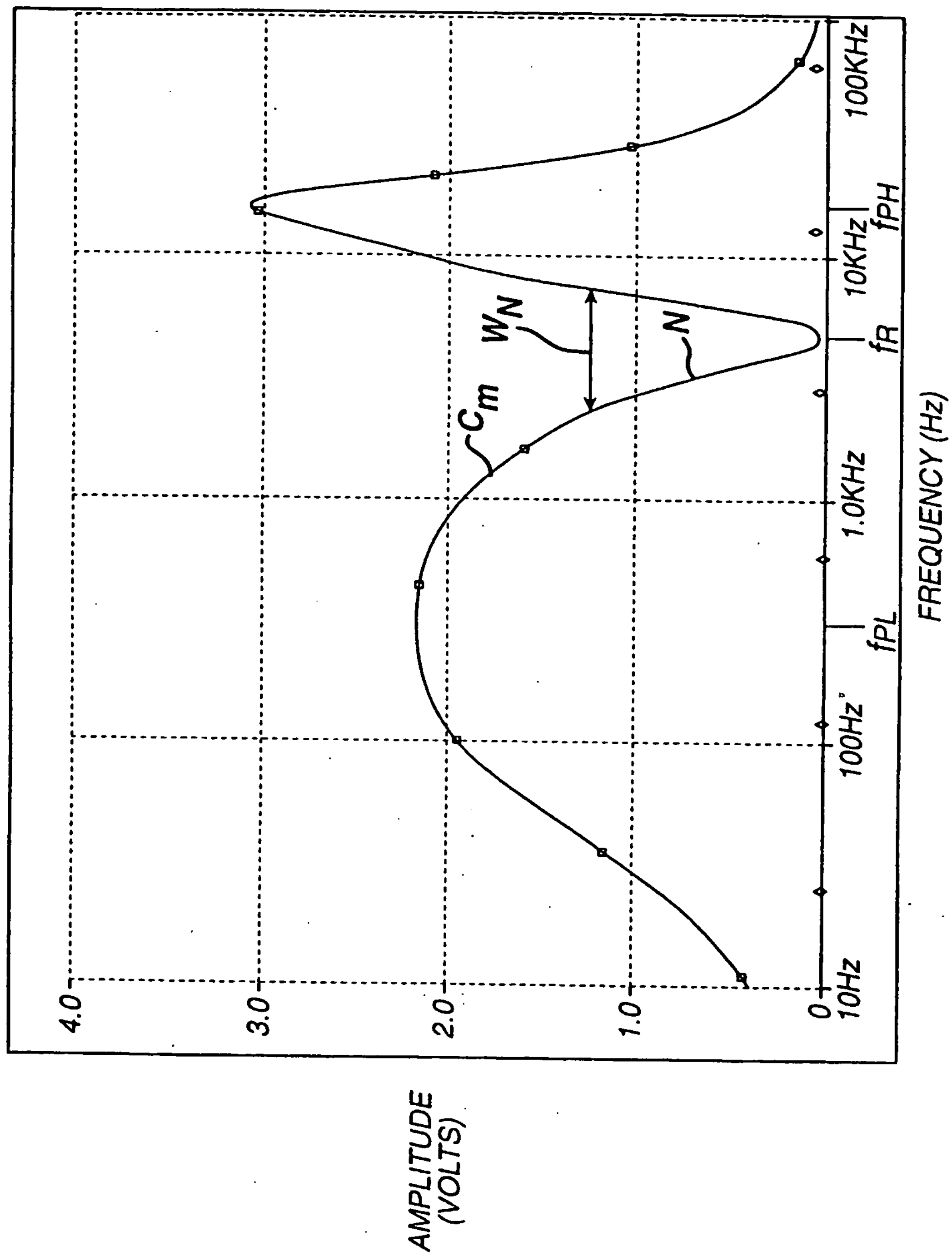

4.0
3.0
2.0
1.0
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
f_{PL}
f_R
f_{PH}
C_m
W_N
N
FREQUENCY (Hz)
AMPLITUDE (VOLTS)

FIG. 29

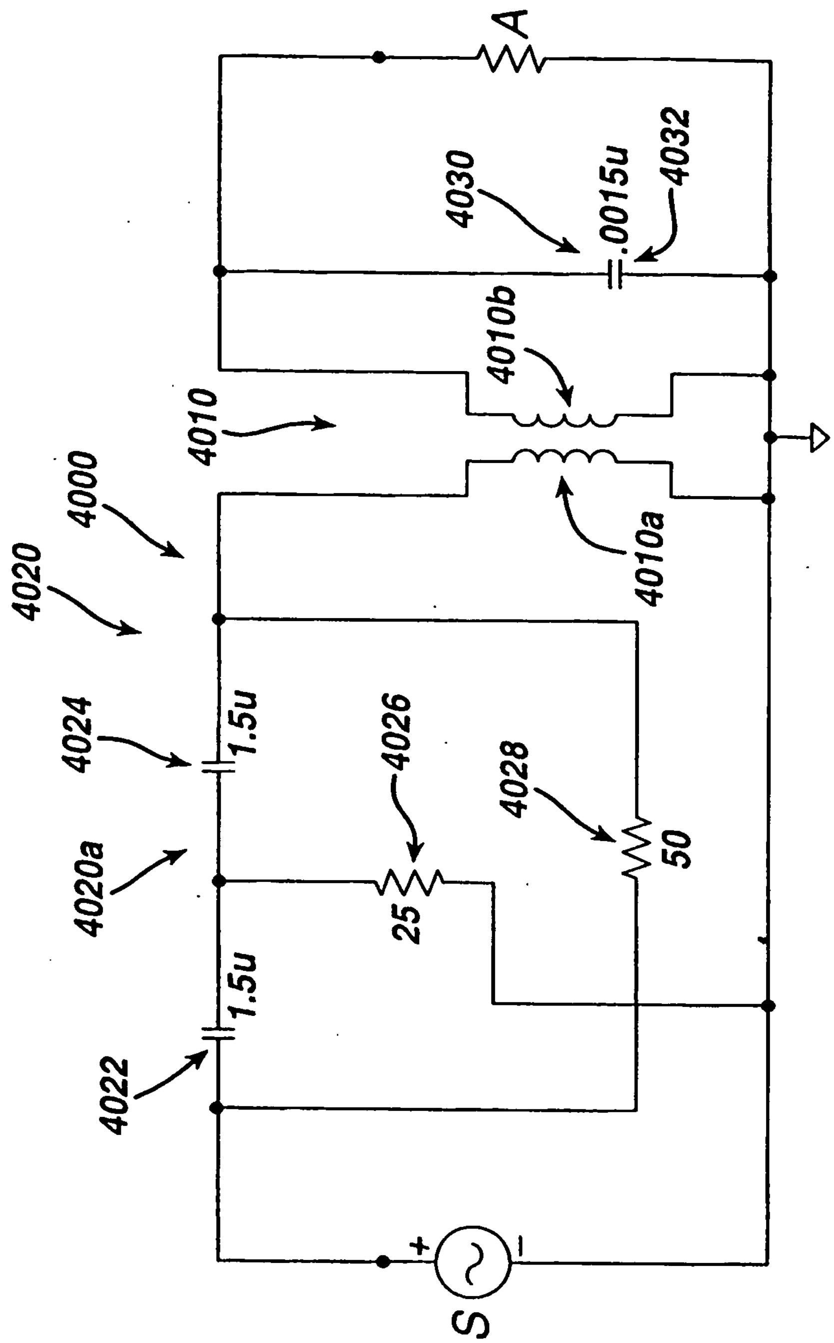

A
4030
.0015u
4032
4010b
4010
4000
4020
4010a
4024
1.5u
4026
4028
50
4020a
25
1.5u
4022
+
S

FIG. 30

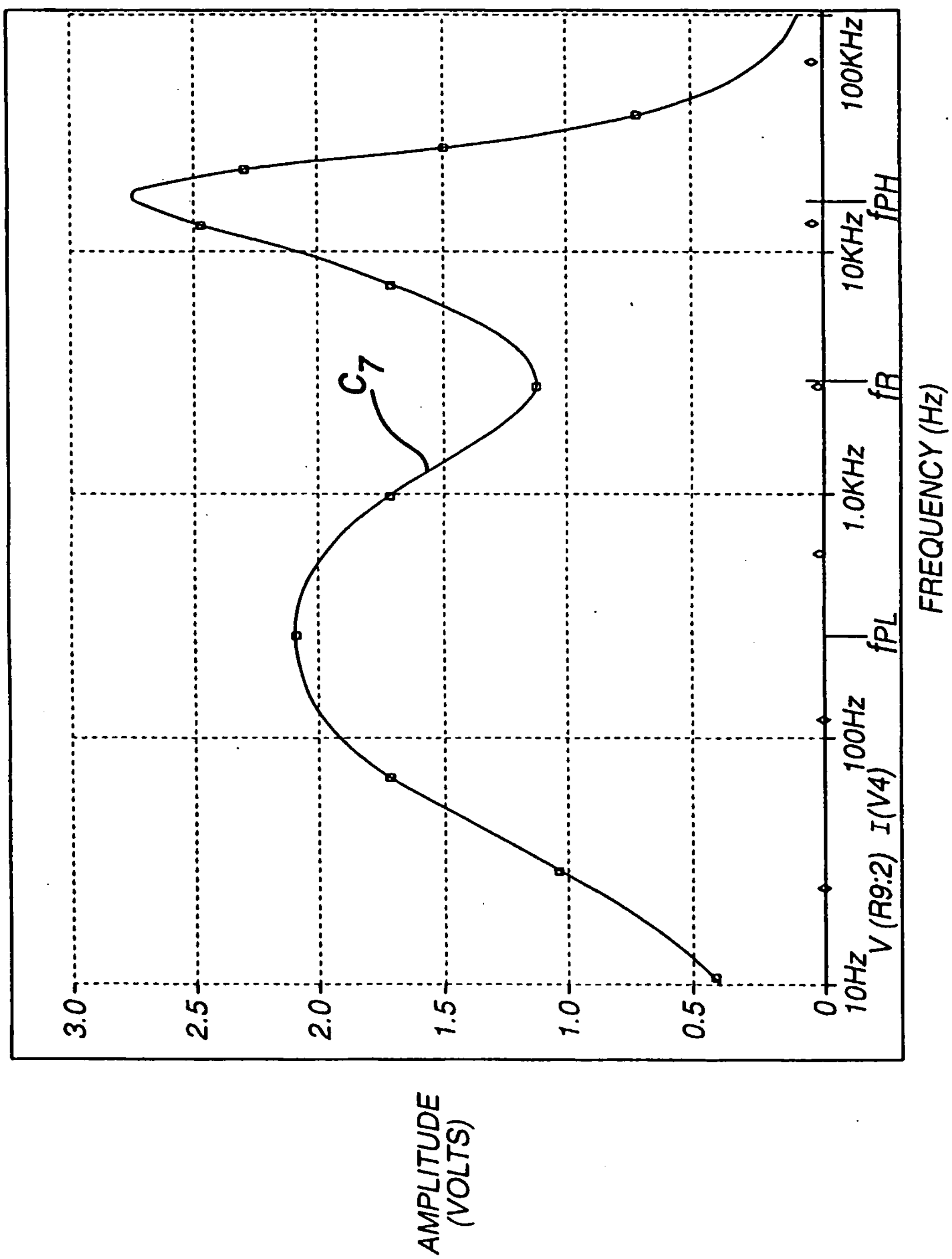

AMPLITUDE (VOLTS)
3.0
2.5
2.0
1.5
1.0
0.5
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
fPL
fR
fPH
FREQUENCY (Hz)
V (R9:2) I(V4)
C7

FIG. 31

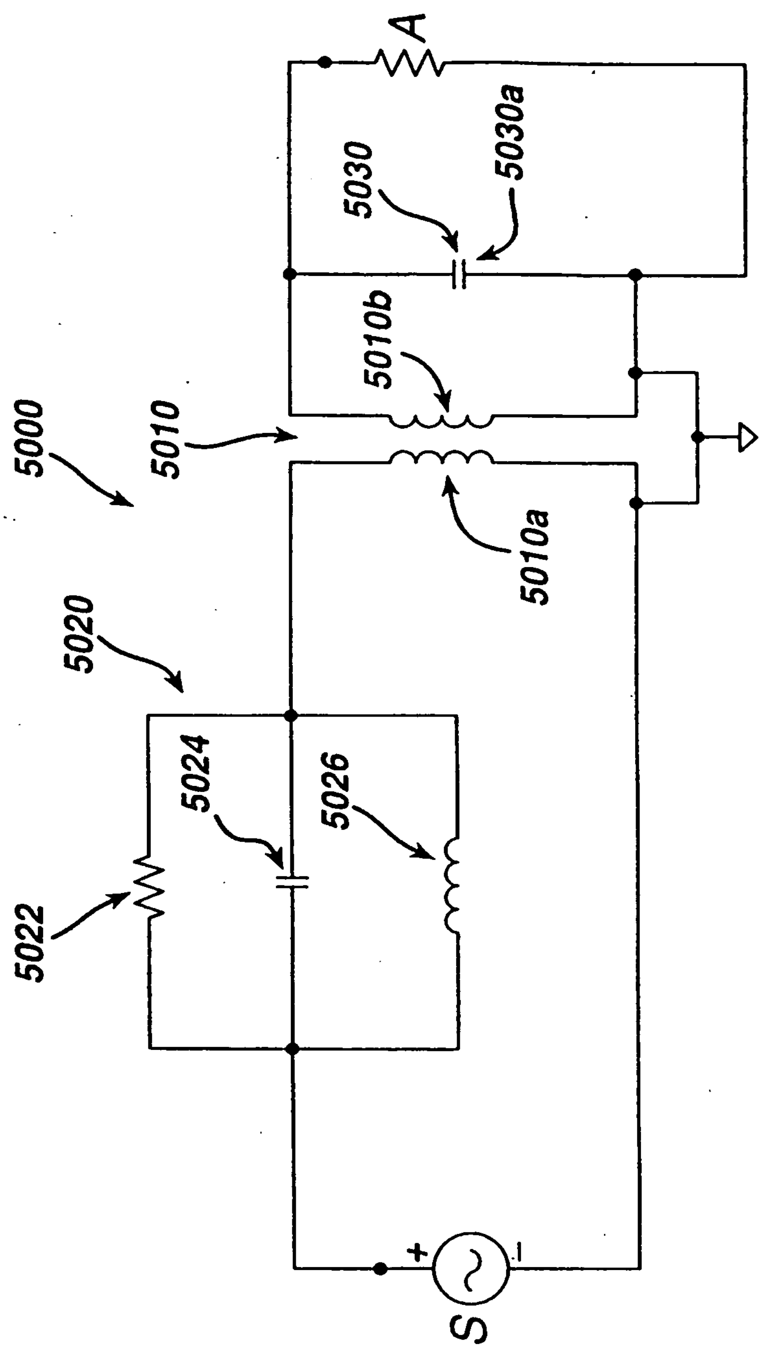
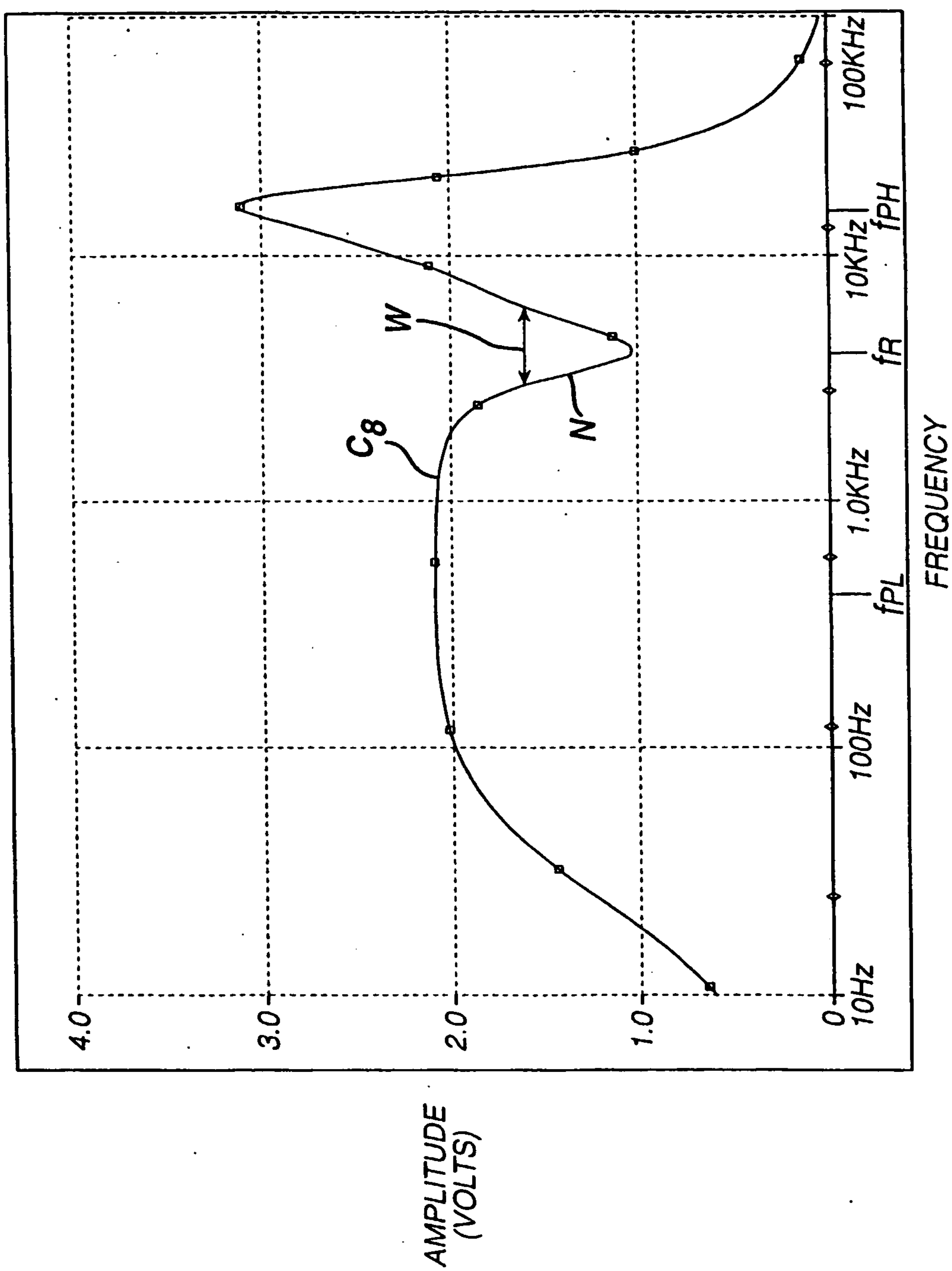


FIG. 32



AMPLITUDE (VOLTS)
4.0
3.0
2.0
1.0
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
fPL
fR
fPH
FREQUENCY
C8
W
N

FIG. 33

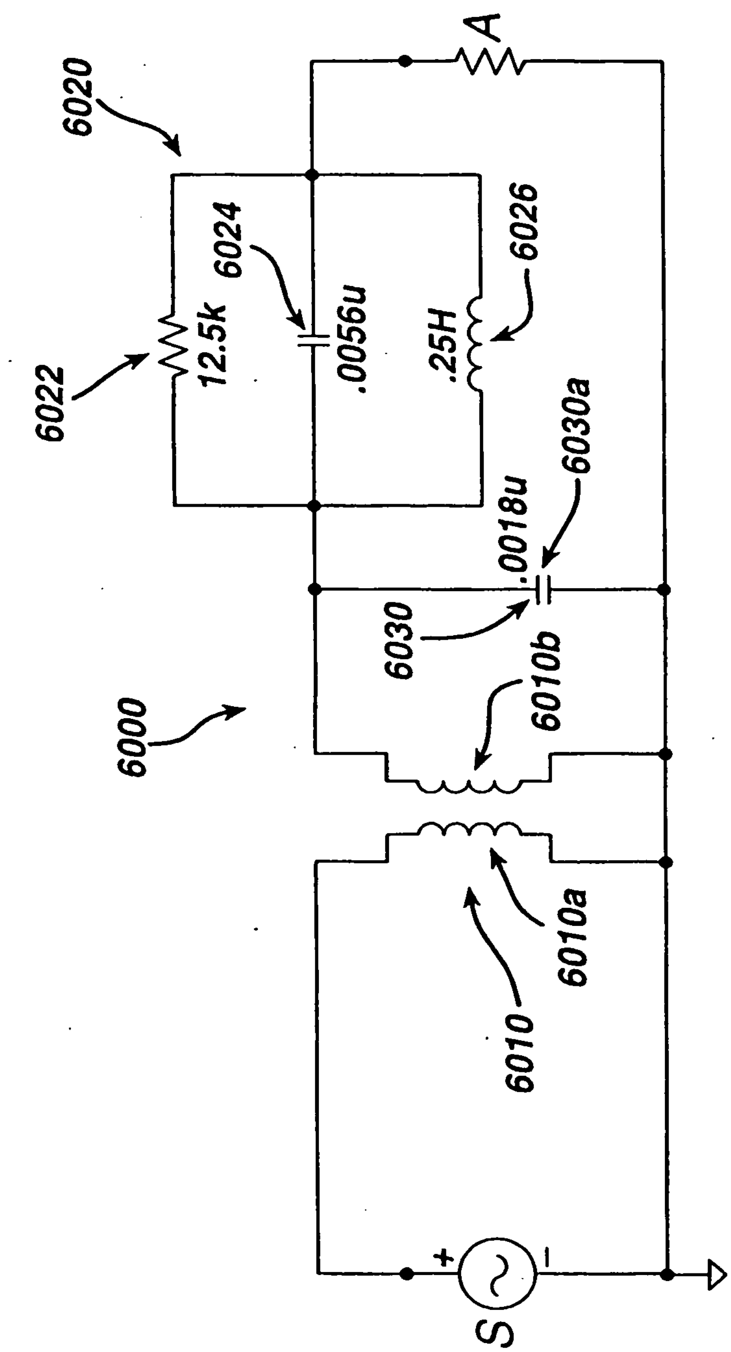

A
6020
6022
12.5k
6024
.0056u
.25H
6026
6030a
.0018u
6030
6010b
6000
6010a
6010
S
+
-

FIG. 34

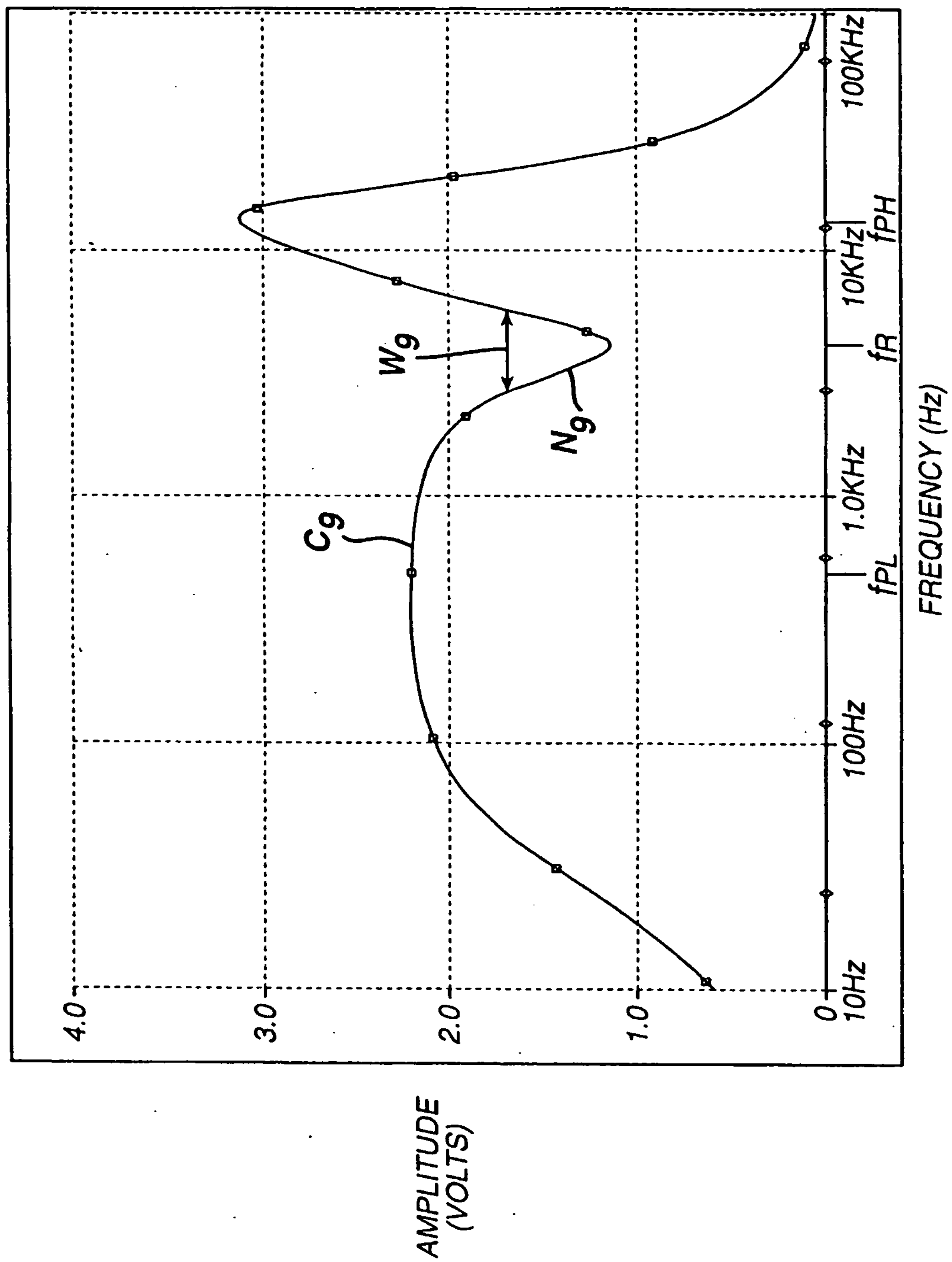

AMPLITUDE (VOLTS)
4.0
3.0
2.0
1.0
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
fPL
fR
fPH
FREQUENCY (Hz)
Cg
Ng
Wg

FIG. 35

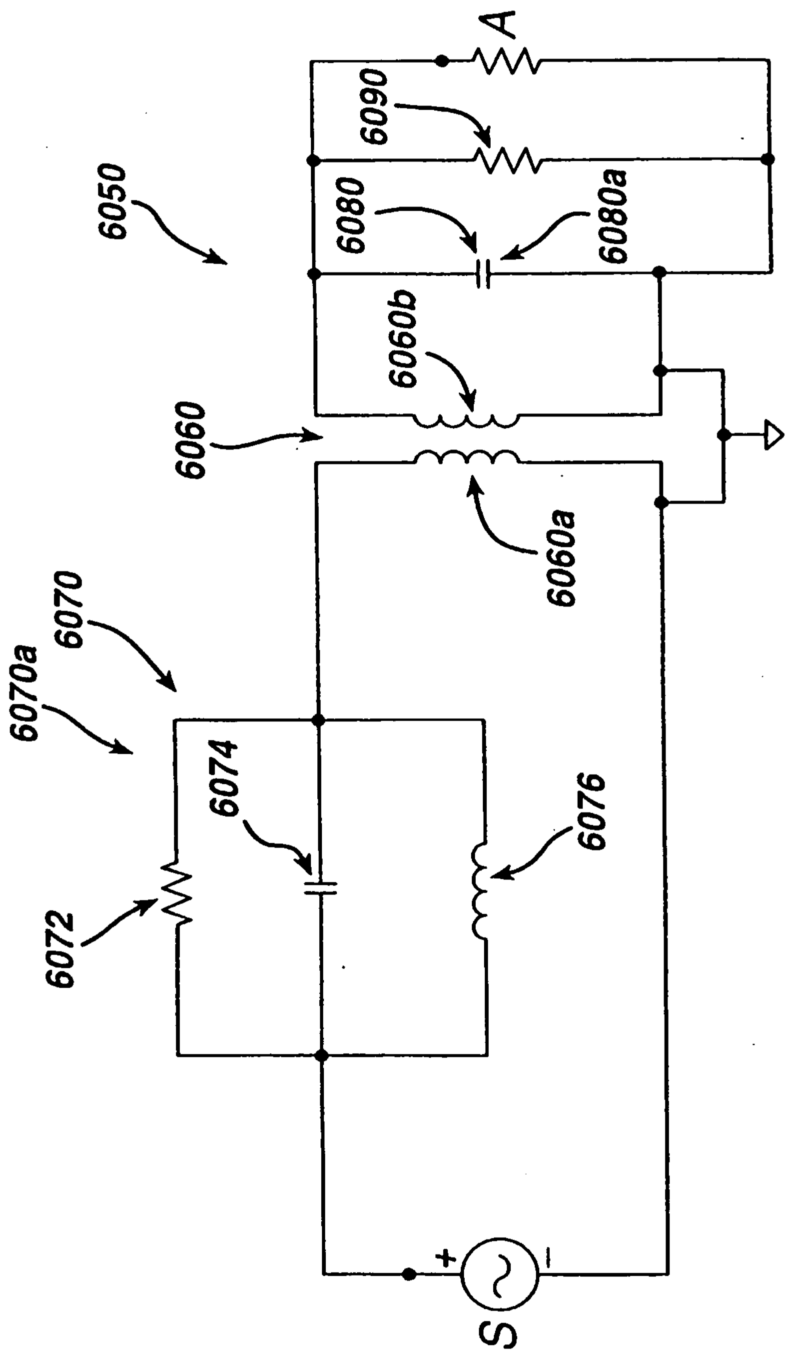

6050
6060
6060a
6060b
6070
6070a
6072
6074
6076
6080
6080a
6090
A
S
+
-

FIG. 36

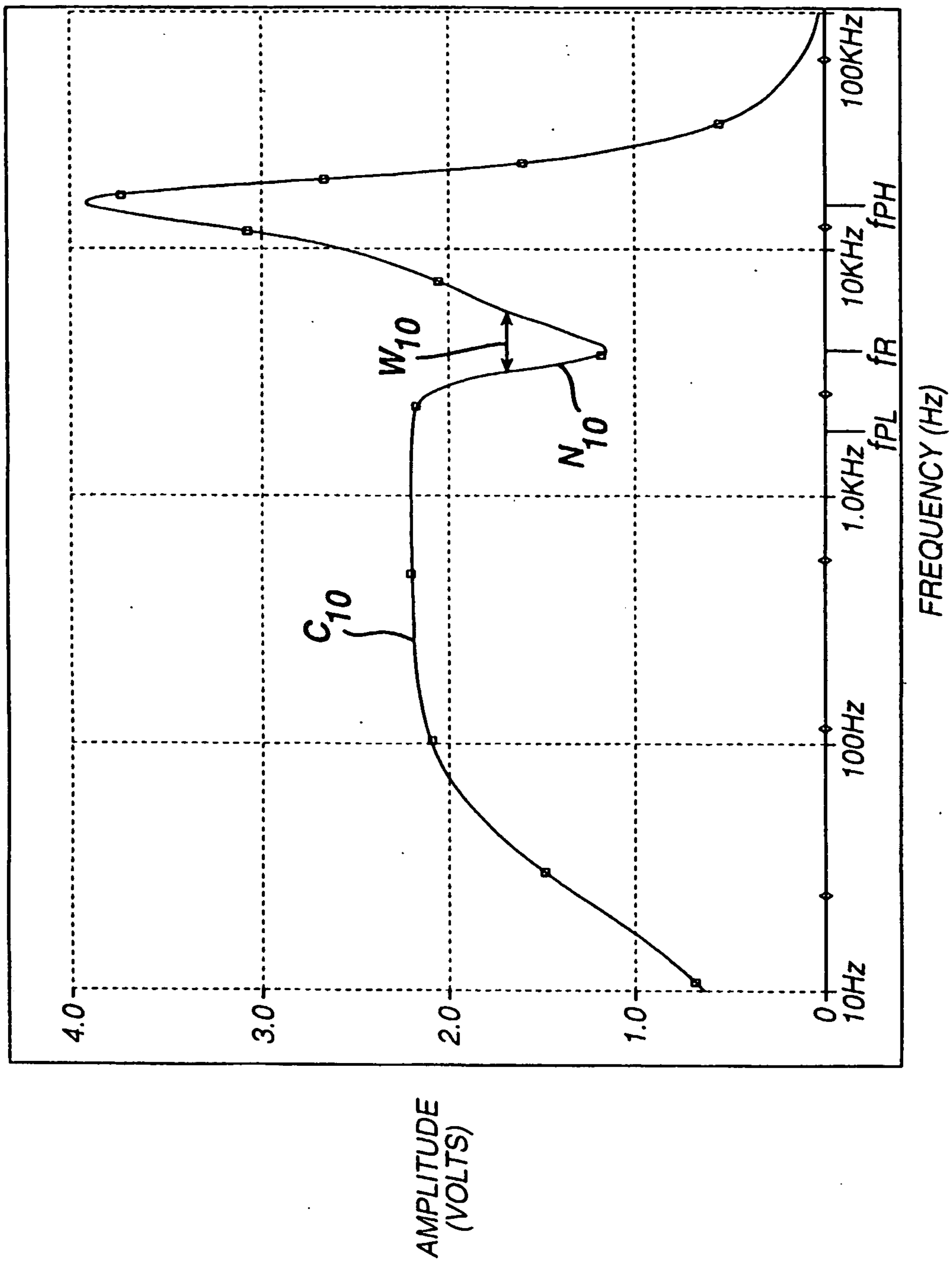

AMPLITUDE
(VOLTS)
4.0
3.0
2.0
1.0
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
f_{PL}
f_R
f_{PH}
FREQUENCY (Hz)
C_{10}
N_{10}
W_{10}

FIG. 37

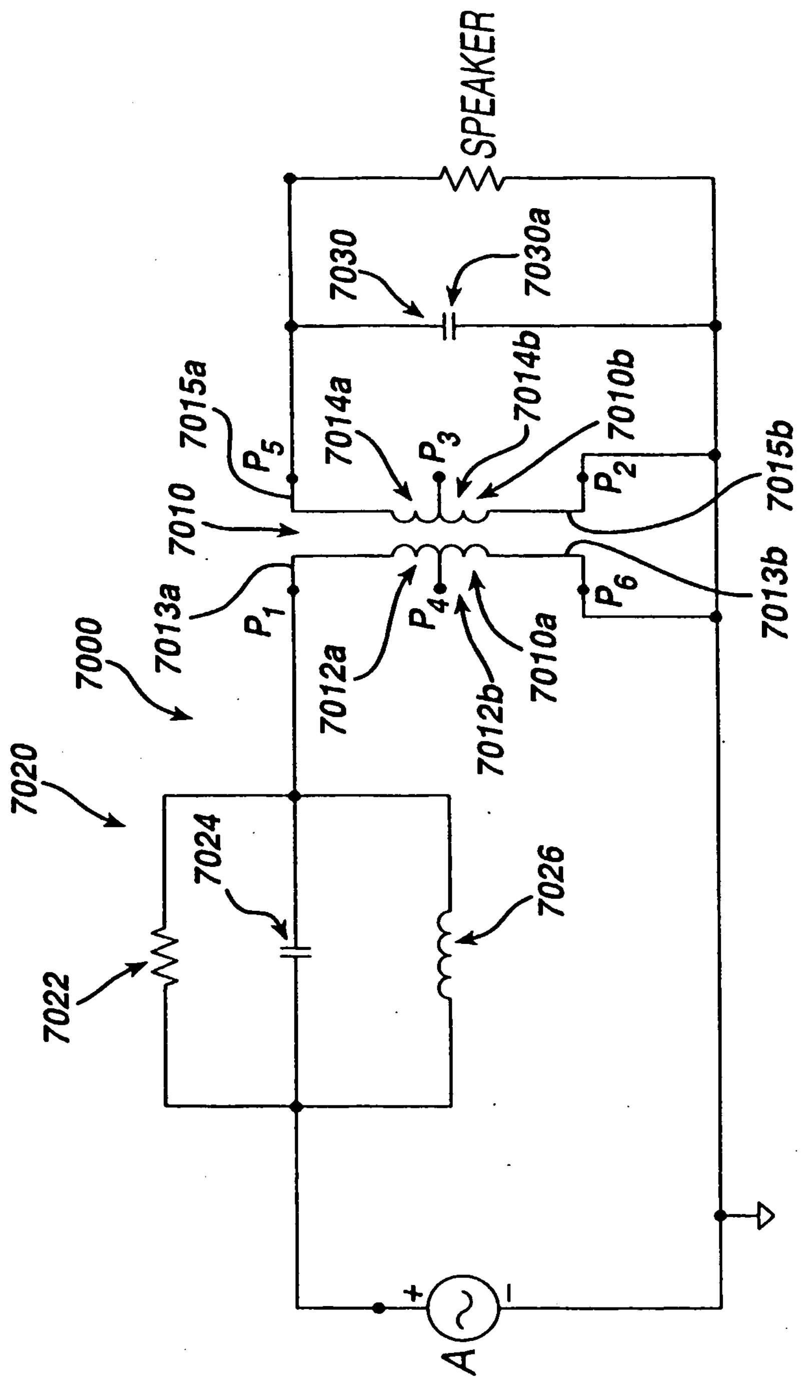

SPEAKER
7030
7030a
7015a
7014a
P_5
P_3
7014b
7010b
P_2
7015b
7010
7013a
P_1
P_4
P_6
7013b
7000
7012a
7012b
7010a
7020
7024
7026
7022
A

FIG. 38

FIG. 38A

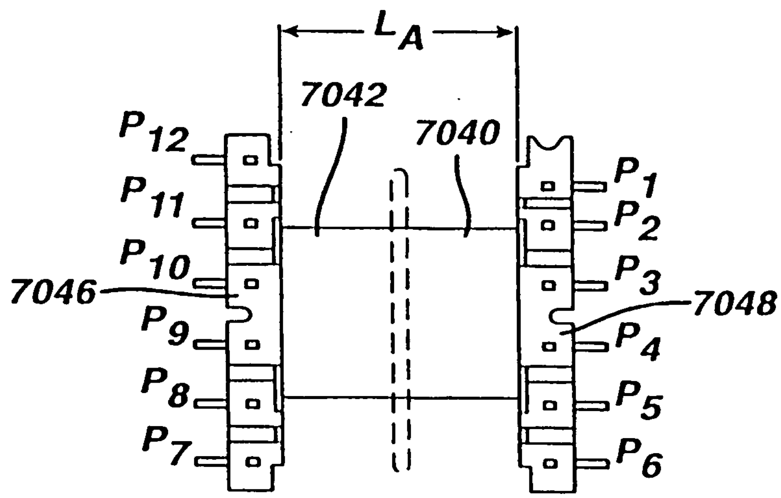
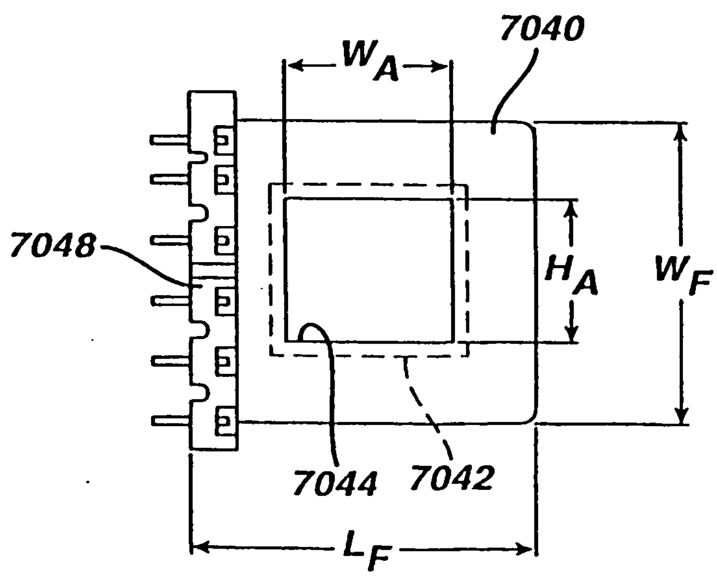


FIG. 38B



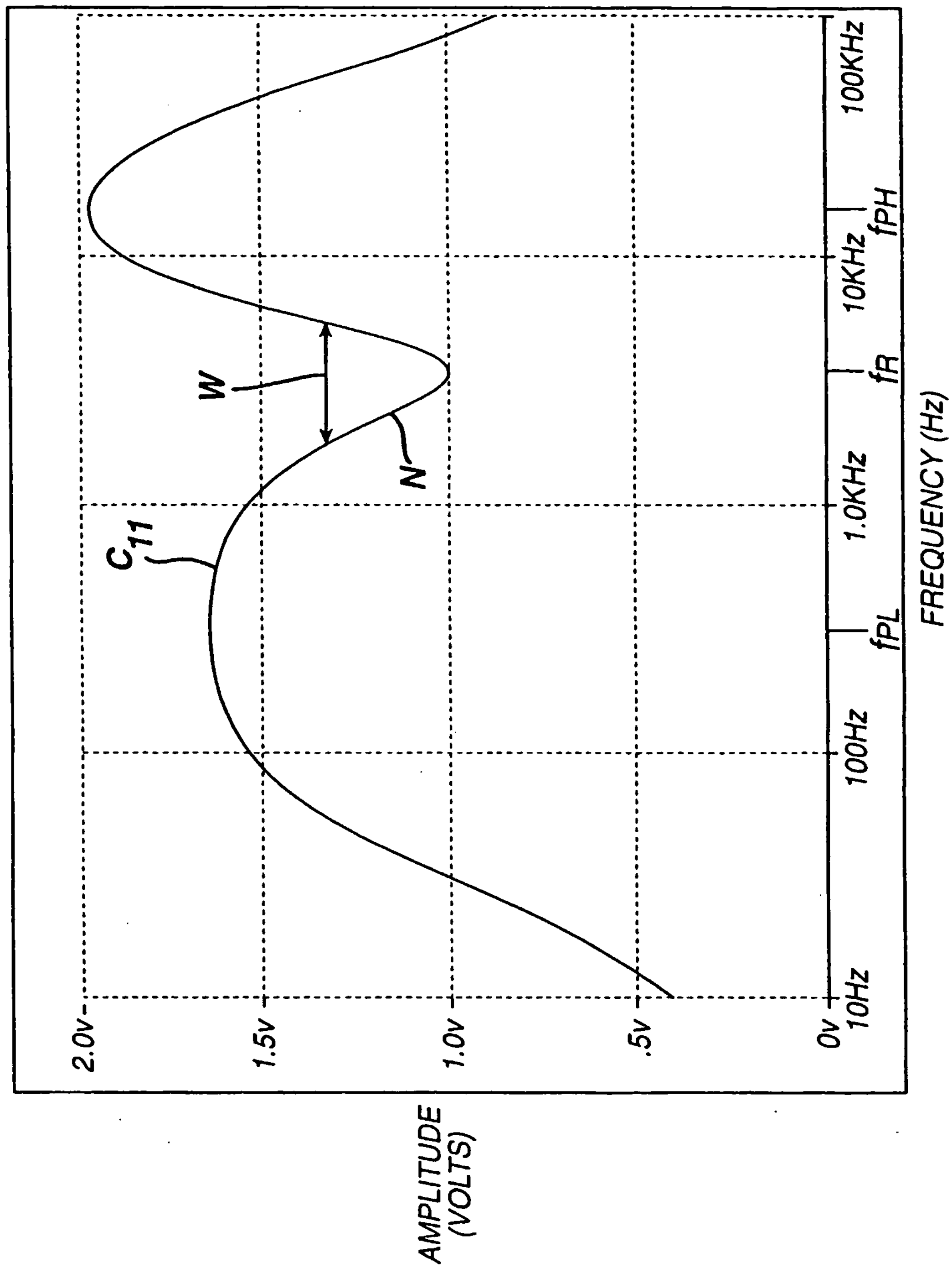

AMPLITUDE (VOLTS)
2.0v
1.5v
1.0v
.5v
0v
10Hz
100Hz
f_{PL}
1.0KHz
f_R
10KHz
f_{PH}
100KHz
FREQUENCY (Hz)
C_{11}
W
N

FIG. 39

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G10H1/12 H03H9/09

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G10H H03G H03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99 30414 A (TRUE DIMENSIONAL SOUND INC) 17 June 1999 (1999-06-17)	1-4,12, 13,16, 19-25, 28-30, 56,57
A	page 15, line 21 -page 16, line 29; figure 7A	31,58
X	US 5 361 306 A (GARCIA ARTURO J) 1 November 1994 (1994-11-01) cited in the application column 6, line 1 -column 8, line 24; figure 3	31,58
X	DE 20 25 844 A (MANGELSDORFF G) 2 December 1971 (1971-12-02) the whole document	1,12,19, 31,56-58

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 March 2001	27/03/2001

Name and mailing address of the ISA	Authorized officer
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	DE 41 34 578 A (MOELLER STEPHAN) 29 April 1993 (1993-04-29) the whole document -----	1

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DE 4134578	A	29-04-1993	NONE		